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Glass Reinforced Plastics

(Including Boat Construction and Repair)

By R. F. Beale

(Member of Ship Department Admiralty, Bath)

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DRAUGHTSMEN'S AND ALLIED
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SECTION I.

INTRODUCTION.

1. Glass reinforced plastics have a number of advantages over other materials and their use has increased enormously in recent years to include the kitchen sink and boats up to 70 ft. in length.

2. This pamphlet describes :—

Components forming the reinforced plastic : their relative merits.

Manufacture : methods, inspection, precautions and faults.

Application : with special reference to boat construction.

Repair techniques.

Design.

SECTION II.

GLASS REINFORCEMENT.

Various materials are in use for reinforcing plastics, natural fibres (cotton and silk), synthetic fibres (rayon, nylon, Orlon, Terylene, cellulose) and mineral fibres (glass, asbestos, etc.). Glass fibres have a number of advantages, being dimensionally stable, non-hygroscopic and capable of production in many forms to suit particular end uses.

The glass used in the manufacture of glass fibres is of two types, low alkali borosilicate glass (known briefly as 'E' glass), having less than 1% alkali content, and high alkali glass (known as 'A' glass), having an alkali content of between 8% and 15%.

The low alkali glass is used where good weathering, exposure and electrical properties are required of a laminate and high alkali glass where good acid resistance is necessary. The glass referred to in this article is mostly of the low alkali content.

Glass fibre is produced in two forms, **Staple Fibre** (*i.e.*, broken into short lengths) and **Continuous Filament.** The glass fibre used for the reinforcement of plastics is almost entirely the continuous filament type. Staple fibre is weak and only used in a form to impart improved surface finishes.

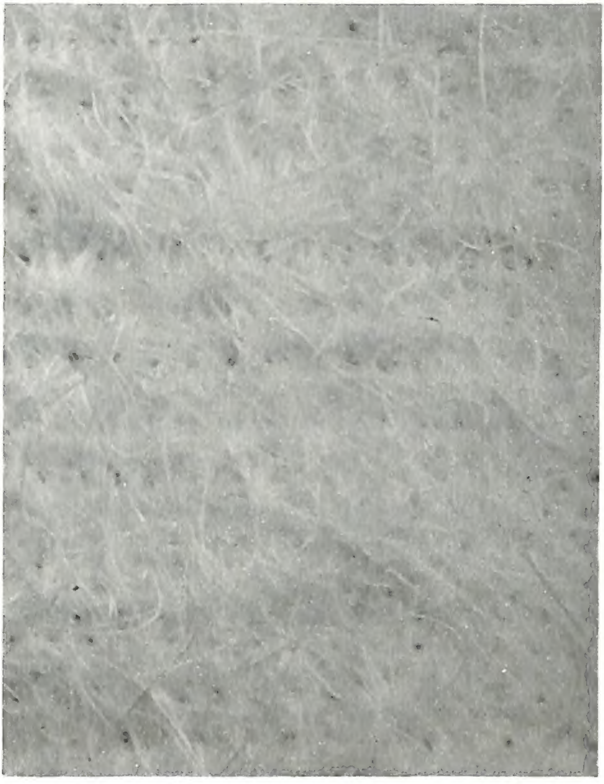
Continuous filaments are produced in two forms—**Rovings** and **Yarns** :—

Rovings are strands of filaments put together parallel without twist, and can consist of any number of strands from five up to sixty or more. They are usually **sized** to facilitate handling and the subsequent impregnation with resin. Two basic types of size are in use, the **general purpose** for use with all types of resins, and a special **high performance** primarily designed to give improved bonding of polyester resins to the glass reinforcement, resulting in high strength of laminates, but which can also be used with other types of resin.

Yarns are strands of filaments twisted together. The twisting operation can be carried out singly, *i.e.*, 2-3-4 or 5 strands can be twisted to form a yarn or twisted yarn can again be twisted together to form multiple yarns in a variety of combinations. Yarns are almost invariably made into fabrics for use generally in reinforced plastics. The "textile size" which is applied to the yarns to permit weaving without damage, unlike the size referred to for rovings, is not normally compatible with resins and has to be removed either by a heat or a washing process. **Finishes** suitable for the desired end product may then be applied. The correct choice of finish is very important in ensuring that the properties required are achieved.

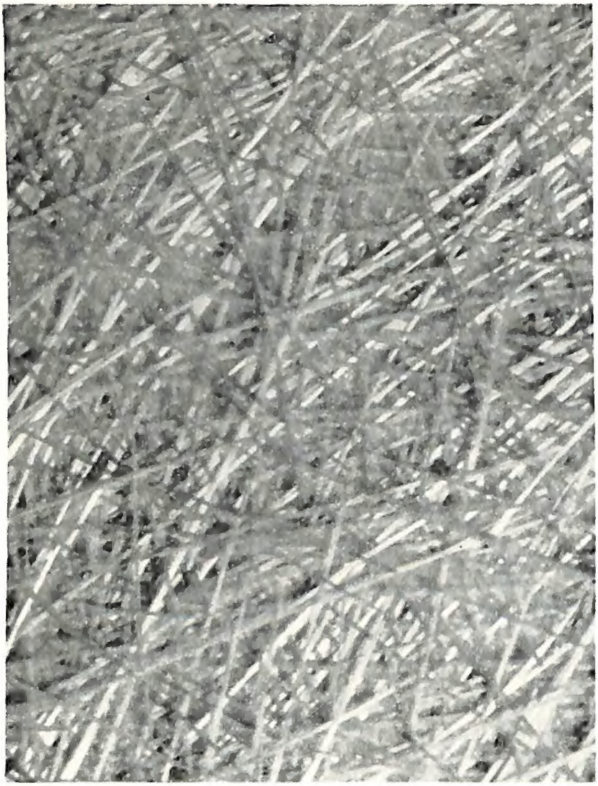
Reinforcement Materials.

The continuous filaments can be chopped into strands ¼″, ½″, 1″ or 2″ long. The shorter strands are normally used with special filled resins as a dough or compression moulding compound. The 2″ chopped strands are used in the production of Needled Mat and Chopped Strand Mat.



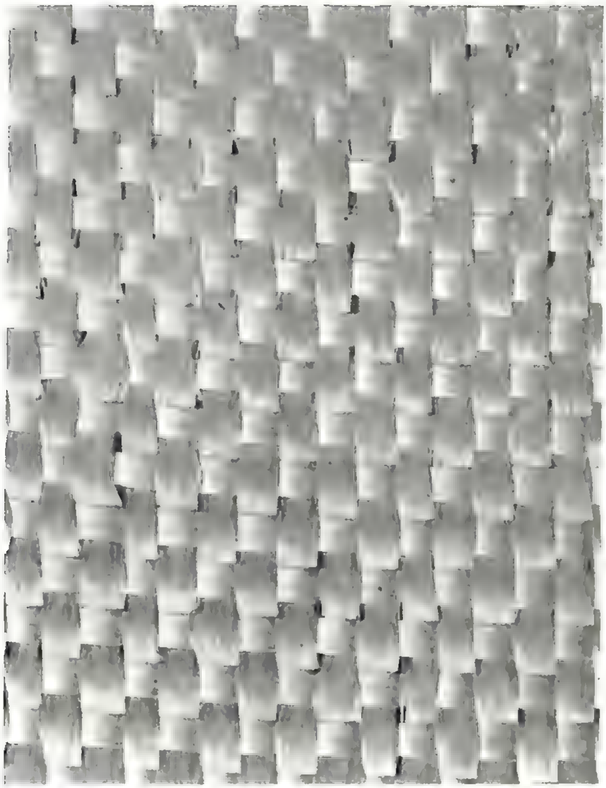
NEEDLED MAT

Needled Mat is composed of the 2″ chopped strands held together mechanically by needling onto a suitable backing material usually cotton, scrim or veil mat. It is more suitable for moulding techniques employing pressure.

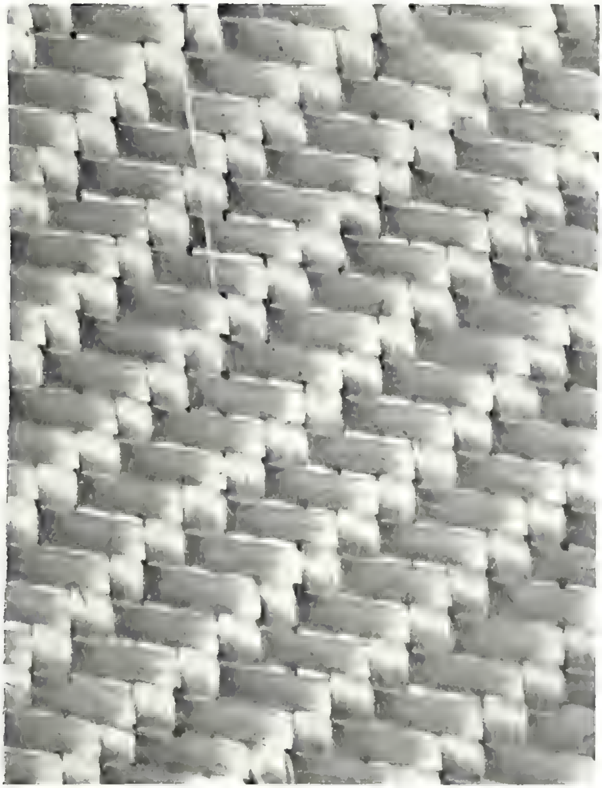


CHOPPED STRAND MAT.

Chopped Strand Mat consists of the 2″ chopped strands randomly distributed and bonded together with a media chosen to provide high performance with low pressure moulding resins. Probably the best filament size is the high efficiency silane type providing good adhesion between fibres and resin. Mat binders are usually designed to provide quick "wetting-out" with the available polyester resins and also perform with certain other resins such as epoxide.



WOVEN ROVING PLAIN WEAVE.

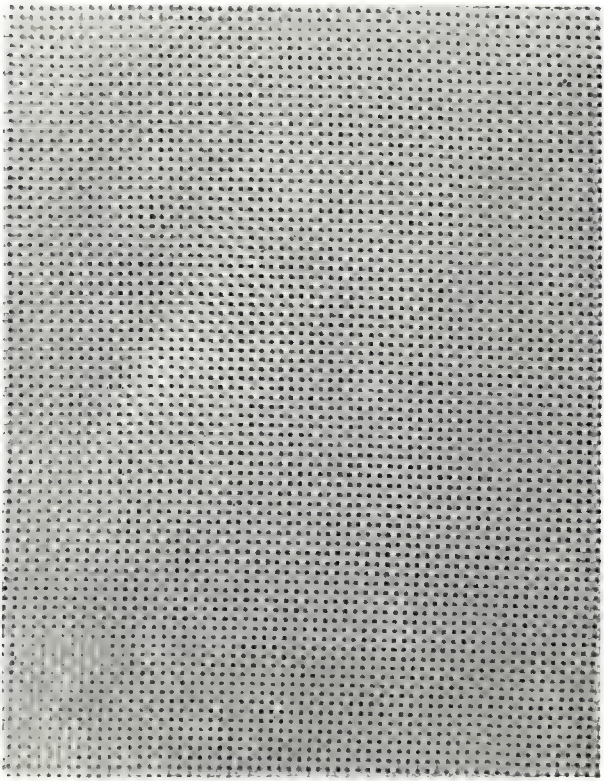


WOVEN ROVING, 3 × 1 TWILL WEAVE.

Woven Rovings are produced from rovings which being available in various compositions, *i.e.*, filament diameter and number of strands, together with the different weaves that can be applied, results in a number of woven roving materials being available. The size applied to the roving does not require removal for weaving purposes making heat treatments and finishing processes unnecessary.

Woven Fabrics.

Woven fabrics are produced from yarns. Many kinds, based on various types of weave, are available. The kinds in most general use are described below.

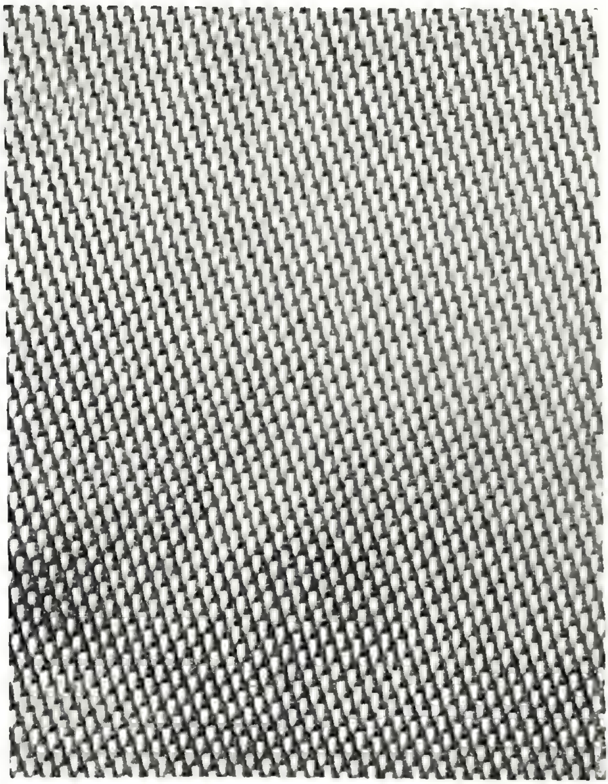


PLAIN WEAVE.

Plain Weave where each warp and weft passes over one yarn and under the next yarn. If the warp and weft yarns are equal in number and count, then the cloth is said to be balanced ; not all plain weaves are balanced cloths.

TWILL WEAVE.

Twill Weave where the warp and weft yarns which pass over each other are varied, 2 over by 2 under being the standard for most applications. It is recognized by diagonal lines passing across.

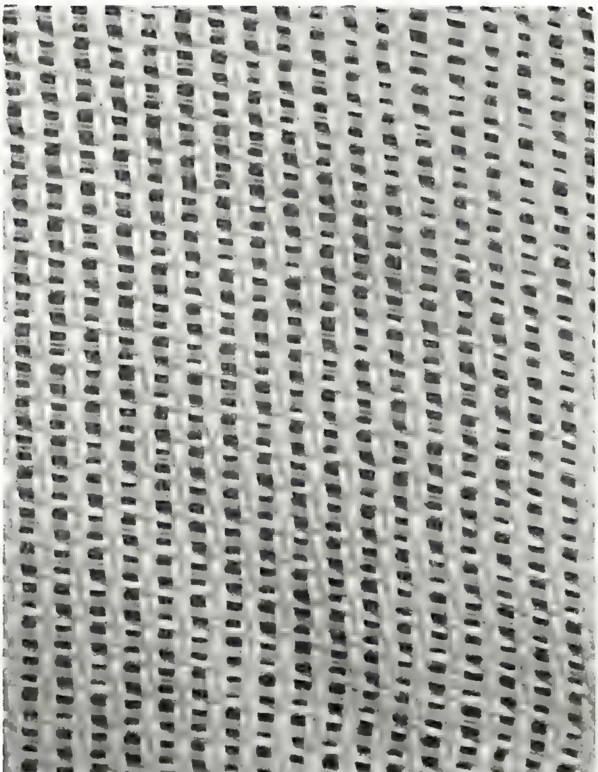


SATIN WEAVE.

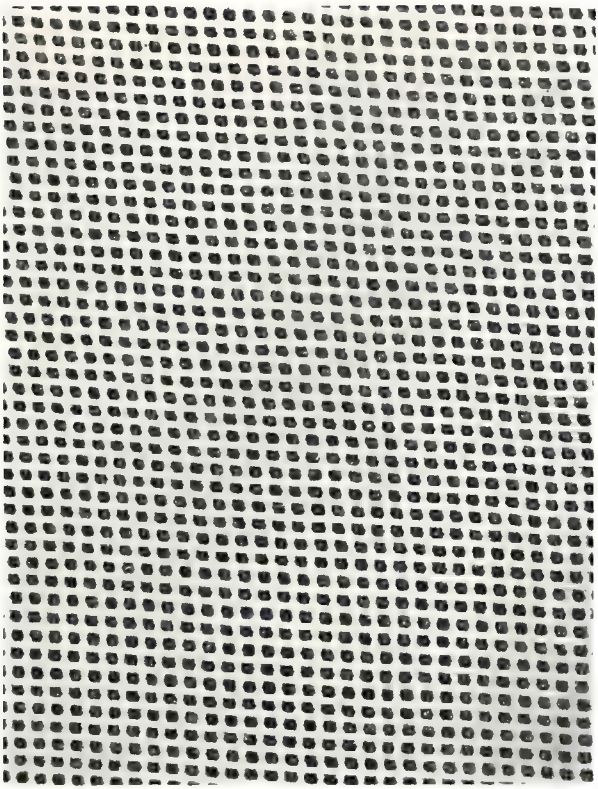
Satin Weave where each warp and weft yarn goes over one yarn and under a number of yarns. Over one and under seven is becoming established as a standard.

UNI-DIRECTIONAL WEAVE.

Uni-directional Weave where strong warp strands are held together by lighter weft strands. Plain, twill and satin patterns are available in uni-directional weave.



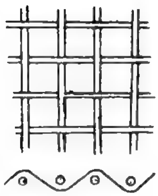
MOCK LENO WEAVE.



TRUE LENO WEAVE.

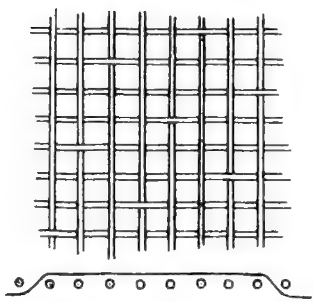
Mock Leno Weave is a fabric which has an open or cellular appearance produced by the way the threads interlace. The threads are usually in groups of 3 or 4 in both warp and weft directions. The effect of the interlocking is to render a very open fabric reasonably stable mechanically.

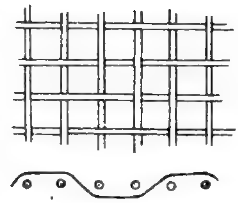
Where the fabric is required to be very fine, as in gauze, the leno construction is used ; this is expensive, however, so mock leno construction is generally preferred.



PLAIN WEAVE

8 END SATIN WEAVE





2 x 2 TWILL WEAVE

Woven fabrics are described by the weave pattern, the number of yarns per inch in warp and weft and the yarn count, *e.g.*, plain weave 42 ends 225—3/4, 36 picks 225—3/4.

The yarn system is one in which the count is the number of 100 yard hanks of the basic strand per pound. Thus a strand giving 22,500 yds./lb. is 225s count. The yarn 225—3/4, has three strands twisted together in one direction, and four of these then "doubled," *i.e.*, twisted back together, in the reverse direction. The yardage of the yarn is 22,500÷12, *i.e.*, 1,875 yds./lb.

The particular features of the various types of glass reinforcement readily available which should enable a choice to be made with reference to method of manufacture and nature of end product are summarised overleaf.

TYPE	FEATURES	CURRENT APPLICATIONS
Chopped strands	Suitable for mixing with resins to form doughs or 'premix.' Good properties for small match metal mouldings. Useful as fillers.	Small compression mouldings. Castings and pottings. Fillers of cavities.
MATS—chopped strand	Low cost. Good bulk and impact strength. Uniform (but low directional strength). Good appearance in translucent sheeting (where a binder of high solubility in resin is used). Good properties for match die moulding. Resin/glass ratio relatively high (new types being introduced with improved wetting out properties and compatibility with epoxide resins).	Ships' boats (generally up to about 25-30 ft. in length). Private and pleasure boats (produced in large numbers up to 20-25 ft. in length—a few well in excess of this size). Car bodies, motorcycle screens and commercial vehicles. Compression mouldings. Moulds for large laminates. Castings. Pipes by centrifugal casting.
—needled	Mechanical keying gives good drape properties. Has high resin pick-up and good resin bond features. Good bulk. Ideal for pressure moulding techniques. Pressure required for good surface finish.	Larger laminates using vacuum or pressure bag principles.
Woven Roving Fabrics	Price range intermediate between mats and cloths. Frays considerably on cutting. Good strength, but because of crimp not as high as obtainable with cloths. Good bulk. Drapes well. Available in balanced or uni-directional weave.	Used in preform process. Sometimes combined with chopped strand mat for boat construction and other large laminates where higher strength required.

TYPE	FEATURES	CURRENT APPLICATIONS
WEAVES—plain	Uniform strength in all directions with balanced weave. Available in uni-directional weave. High strength. Good "wetting out" properties (with the exception of very tight weaves). As scrim (a thin plain weave) gives good surface finish. Available as "tapes."	Strength laminates. Radomes. Scrim-surface finishes. Tapes—tubing, air ducting, etc.
—satin	Uniform strength in all directions with balanced weave. Available in uni-directional weave. Reduced crimp (waviness in weave) as compared with plain weave, produces higher tensile and flexural strengths. Good drape properties (in cases of double curvature). Good appearance and smooth surface finish.	Strength laminates. Radar reflectors. Straight columns (uni-directional weave).
—twill	Good strength properties. Available in uni-directional weave. Good drape characteristics. Weave stability not so good as plain weave. Surface finish of laminate not smooth.	
—mock leno	No distortion of weave or fraying (because of mechanical keying). Wets out easily. Open weaves tend to produce resin rich areas. Closer weaves available for higher strengths.	Sheathing with epoxide resin.

In general, chopped strand mat is used where high impact strength and/or low cost is required, and a cloth is used either in whole or in part where tensile and compressive stresses are important. Optimum strengths are obtained by a combination of factors involving thickness and weave. Interlamina strength is important in some designs of cloth moulding.

Availability in Trade.

Mats are available in weights of 1 oz., $1\frac{1}{2}$ oz., 2 oz. and $2\frac{1}{2}$ oz. per square foot. Surfacing mat 0·012 inch thick is generally available, but 0·020 inch thickness can be obtained.

Woven fabrics are available in weights varying from 1 oz. to 2 lbs. per square yard.

Specification D.T.D. 5518 lists a number of low alkali plain, twill and satin weaves which are readily available. The specification also gives the thickness, weight per sq. yard and minimum breaking strength.

SECTION III.

RESINS.

The resins used in glass reinforced plastic construction are thermosetting. The most common types used are polyester and epoxide and these are described below. Other resins are phenolics, melamines, silicones and furanes.

POLYESTER RESINS.

Esters are formed by the reaction of an acid and an alcohol. Complex esters, generally termed **polyesters** are formed when polybasic acids are reacted with polyhydric alcohols. The raw materials generally originate from the coal tar and petroleum industries. As numerous acids and alcohols can be used, a variety of polyesters can be made available and these have distinct physical properties which fit them for particular applications. Polyester resins may vary from water white to straw colour and their consistency may vary from that of thin to thick treacle depending upon type.

A Catalyst is required to be added to the polyester resin in order to promote the three dimensional cross-linked structure which is a characteristic of thermosetting resins. The type of catalyst must be appropriate to the resin used and to the method of production and the advice of the resin manufacturer should be taken. Catalysts can be obtained in liquid, paste or powder form. They are usually powerful oxidizing agents ; contact of such catalysts with the skin or finely divided organic materials or metals should be avoided. Care should also be taken that peroxide catalysts are not spilt on flammable materials.

The Cure is the name given to the setting of the resin and the full chemical reaction which takes place. Heat in some form is often applied to produce the cure, but is not essential. Complete cure can be effected with selected resins at temperatures of not less than 60° F. The chemical reaction of such resins produces internal heat (exotherm).

The curing of polyester resins is usually associated with a volatile chemical (styrene) which is required in correct proportions to facilitate full cross-linking of the molecules. The loss of this chemical by evaporation has marked results on the ultimate strength of the laminate ; the control of temperature and the prevention of draughts during the cure are accordingly of great importance.

The cure of polyester resins can be accelerated by **externally applied heat** (post-heat). Curing can be retarded, and sometimes prevented by the following factors :—

Working Conditions—temperature below 60° F., cold draughts, high humidity.

Resin Mix—insufficient catalyst and/or accelerator ; unsuitable types of fillers ; fillers which have absorbed moisture.

Reinforcement—dampness of the glass reinforcement.

Presence of certain Materials—phenols (particularly dihydric phenol), phenol formaldehyde resin dust (from sanding glued wood), sulphur, most forms of carbon black, rubber, metallic copper or copper containing alloys, resorcinal glues, uncured epoxide resins and putty.

An Accelerator has to be added to resins required to set at room temperature to enable the appropriate catalyst to work at a controlled speed. Accelerators are normally liquids and the amount to be added to the resin mix is determined by the conditions of the work, temperature and humidity. Accelerators should be chosen to suit the particular resin and, as in the case of catalysts, the advice of the resin manufacturer should be taken.

Thixotropic Agents are added when laying up is required on sloping, vertical or overhead surfaces to prevent drainage of the resin. This additive, provided it is not in the form of a filler, or is used in excess, has little effect on the strength of the laminate and most resin manufacturers have an agent appropriate to the resin.

Fillers may be incorporated in resins for a variety of reasons, the more important of which are :—

(i) reduction in cost,

(ii) improvement of particular physical properties (thermal conductivity, thermal expansion, electrical resistance, abrasion resistance, surface hardness, fire resistance),

(iii) reduction of exotherm.

Disadvantages arising from the use of fillers are :—

(i) difficulty in working, due to increase in viscosity.

(ii) water absorption may increase (when hygroscopic fillers are used),

(iii) reduction in tensile and impact strengths (with non-fibrous filler).

Flexibilisers, usually in the form of a flexible polyester resin, may be added to a rigid polyester resin to increase resilience, *i.e.*, prevent crazing of the external resin coat, etc. Its addition is usually to the detriment of the water absorption properties.

The Mix is the expression often used in the industry when referring to the prepared resin, catalyst and accelerator mixture.

On no account should the catalyst and accelerator be mixed together, as they produce a self-explosive mixture. The catalyst (or the accelerator) should first be thoroughly mixed with the polyester resin, and the accelerator (or catalyst) added and mixed.

Physical Properties.

The more important physical and other properties of polyester resins may be summarised as follows :—

Abrasive Resistance. This is not high, but can be improved by the use of appropriate filler (*e.g.*, powdered alumina, slate powder, sand, etc.), or surface reinforcement (*e.g.*, Terylene, Dynel or spun rayon, etc.).

Adhesion. If glass reinforced polyester resin laminates are not fully cured it is possible to employ polyester resin as the bonding agent. If the cure is well advanced, it would be advisable to score the laminate on the interface to give additional mechanical key. If the laminates have fully cured, a polyester resin can be used as an adhesive, but is dependent upon good working conditions and the nature of the cured material. It is preferable in such circumstances to use an epoxide resin system as an adhesive.

Polyester resins will not adhere to cured epoxide resin : a special keying material has to be interposed in order to achieve adhesion.

Chemical Resistance. Polyester resins vary in their chemical resistance. Selected types are available which are resistant to water, aqueous non-oxidizing acids, alkalis, metal salt solutions, formaldehydes, glycols, bleaching agents and some solvents (except certain chlorinated solvents and ketones). It is advisable to test the chemical resistance of the fully cured polyester resin in each individual case.

Electrical Properties. Polyester resins have useful electrical properties and are being used to an increasing extent in this field of application particularly where electrical stress is low and ease of lamination is required.

Fire Retardation. Fillers such as antimony oxide and chlorinated hydrocarbon are added as fire retardants to polyester resins. Self-extinguishing polyester resins are available. They are more expensive. Their weathering properties are, in some cases, lower than the unmodified polyester resins.

Flammability. Polyester resins and their associated catalysts and accelerators are, in general, all flammable, and some of the paste type catalysts present a special fire hazard. The flash point of the resins and the accelerators is about 88° F.

Pigmentation. Polyester resins may be pigmented by the addition of **suitable** materials which are available in liquid, paste or powder form. Most of them slightly retard the setting time, but do not in specified

amounts affect unduly the strength of the resin. Some colours (*e.g.*, phthalocyanine blue) have better weathering properties than others (*e.g.*, ultramine blue). Black pigment should be chosen carefully as carbon black inhibits cure. The advice of the manufacturers should be taken with regard to compatability of pigment with particular resins.

Shelf Life. Under optimum conditions of storage, shelf life may be broadly summarised as follows :—

Resins (unmodified)	....	6 - 12 months
Catalysts liquid form	....	3 months
paste form	....	indefinitely
Accelerators	....	6 months

Exposure to sunlight and heat reduces shelf life considerably.

Shrinkage. Polyester resins devoid of fillers shrink by as much as 7% by volume. The shrinkage tends to pull the resin away from the surface of the glass reinforcement, and from the mould. Shrinkage in laminate construction reveals itself more on thickness of the laminate than on the other dimensions.

Stability. The maximum working temperature at which a polyester/glass laminate will function is dependent upon the loading. General purpose polyester resins will begin to soften at 60° C. Good heat resistant resins at 150° C.

Storage. Polyester resins, their catalysts and accelerators, should be stored in darkness at temperatures not exceeding 20° C.

It is advisable periodically to vent liquid catalysts since gaseous oxygen may be spontaneously liberated during storage. All peroxide catalysts will, if heated, decompose liberating oxygen.

Catalysts and accelerators should be stored separately in view of the explosion risk if they are mixed.

Water Absorption. Selected polyester resins are available which exhibit low water absorption properties.

Industrial Applications.

Boat hulls, canopies and deck houses, aircraft components, car bodies, motorcycle shields, commercial vehicle cab and body components, buoys, radomes, radio components, translucent sheeting, components for chemical industry, food containers, contemporary furniture, ducting rods and tubes, embedding of botanical, anatomical and metallurgical sections, etc.

Polyester resins have been developed which may be used in surface coating applications, *e.g.*, paints.

EPOXIDE RESINS.

The most common method of manufacture of epoxide resins is by the reaction of epichlorhydrin and bisphenol. They are available in forms suitable for "hot set" and "room temperature setting" of various viscosities and are usually of amber colour. They can be modified by the addition of flexibilisers, thixotropic agents, fillers and pigments.

A hardener is required to be added to the resin to produce the three dimensional cross linking of the molecules. Hardeners in common use are aliphatic or aromatic amines or anhydride curing agents. The liquid amine type hardeners commonly present dermatitic hazards, but hardeners of low irritant potential are available. The safest of the "low irritancy" hardeners are those with low vapour pressure, *i.e.*, those which are not only non-irritant through liquid contact but are also non-volatile. Even those hardener systems which are slightly volatile do not present the problems caused by the volatile styrene associated with the cure of polyesters.

The cure and ultimate strength of cold setting epoxide resins are not unduly affected by prolonged gelation as would occur at low temperatures or under draughty conditions. The cure may take several days or weeks ; the application of post heat will accelerate the cure. Some epoxy resins which have gelled will complete their curing underwater, a matter of importance in boat construction.

Materials which inhibit the cure of epoxy resins are very few in number and may be ignored.

Fillers are sometimes incorporated and the remarks as for polyester resins generally apply, except that epoxide resins will accept a higher proportion of filler.

Physical Properties.

The physical and other properties of epoxy resin may be summarised as follows :—

Abrasive Resistance. It is not high but superior to polyester resins. Can be improved by use of appropriate fillers or surface reinforcement.

Adhesion. The adhesion of epoxy resins to a wide range of materials, including cured polyester resin, is very good : so much so that epoxy resins are used to a considerable extent in industry as an adhesive. The adhesion to glass filaments results in laminates of high strength and of considerable resistance to delamination.

Chemical Resistance. Selected epoxide resins possess exceptional all round chemical resistance which does not deteriorate at temperatures up to 200° C. The exceptions are hydrochloric and nitric acid, concentrated sulphuric acid, ammonium hydroxide, acetone, ethyl alcohol and some aliphatics.

(For some requirements, such as high acid resistance, the glass reinforcement has to be specially selected because although the resin may be resistant any exposed glass may be attacked).

Electrical Properties of epoxide resins are extremely good on account of :—

(i) low shrinkage—less tendency to internal cracking and crazing.

(ii) good adhesion to metals and other materials.

(iii) avoidance of gas or water vapour pockets (as no volatile agents are associated with the cure).

(iv) excellent insulating properties.

Hand lay-up methods of production are not normally employed for the higher quality "electrical" epoxide glass laminates.

Fire Retardation. On the basis of recognised tests epoxide resins may generally be regarded as self-extinguishing.

Flammability. Epoxide resins and hardeners in general do not when stored or handled constitute a fire risk.

Pigmentation. Epoxide resins can be coloured using selected pigments. The advice of the manufacturer should be sought with regard to colours and suitability of materials compatible with the resin.

Shelf Life. The shelf life of both resins and hardeners is at least 12 months and often far in excess of this period providing that they are stored under reasonable conditions.

Shrinkage. Epoxide resins exhibit very low shrinkage on curing and their use is recommended where dimensional stability is the prime requirement.

Stability. Epoxide resins are available which remain stable at temperatures up to 250°C., but strength at such temperatures falls off rapidly.

Storage. No particular storage precautions are necessary except that storage at very high temperatures will shorten shelf life, but not below the minimum quoted above.

The retention of heat in epoxide resins when stored in relatively high temperatures will, unless removed by some form of cooling, reduce the working time of the resin/hardener mix.

Water Absorption. Selected epoxide resins are available which exhibit (after appropriate curing) low water absorption properties.

Industrial Applications.

Industries are in many instances adopting epoxide resins with a variation of fillers for the manufacture of moulds for producing castings

and laminations. In this application the resin for the working surface of the mould usually has a filler such as slate incorporated in it to provide a hard surface which may be polished to give a high finish. It has the advantage of reducing the need for film forming parting agents when used for polyester/glass moulding.

It is also becoming extensively used as an adhesive and for electrical components, high strength laminates such as nose domes, etc., in the aircraft industry, special tubing and piping, tooling and repair purposes.

Epoxide resin is now being incorporated in paints and solventless surface coatings.

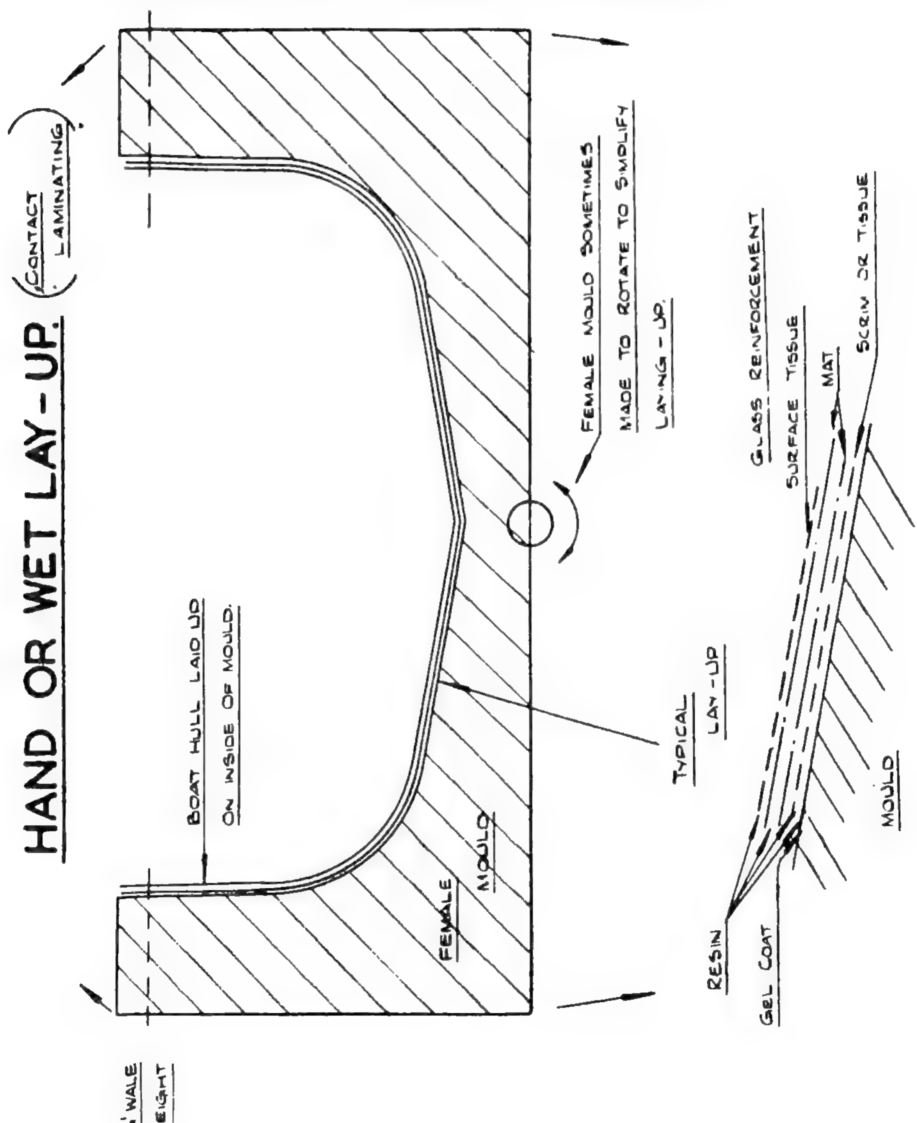
Epoxide resin putty is available which is suitable for filling such as scores in polyester laminates, etc.

SECTION IV.

METHODS OF PRODUCTION.

G.R.P. articles are made in moulds. Except for those made by the matched die process, a good surface finish is produced on one side of the article only ; this is the side of the laminate against the mould, *i.e.*, that which is first laid down. Female moulds are therefore used where good external finish is required.

The following are some of the methods of production used :—



This is the more popular method of production for large structures such as boats, vehicle bodies, etc., as costs for equipment and moulds are at a minimum.

In view of the wide use of this method of manufacture, the process will be given in detail.

Moulds.

The moulds may be produced in a variety of ways using various materials, *e.g.*, female moulds manufactured direct from wood, plaster or metal, etc., or female moulds of G.R.P. produced from actual articles or male formers of wood, plaster, etc.

The choice of materials and techniques is dependent upon the number of articles to be produced and the finish required. It must be remembered that the final article will reproduce any blemishes in the surface of the mould.

Wooden moulds are cheaper and often used for prototypes and where limited numbers of articles are required. Carefully selected timber of low moisture content (about 12-15%) must be used. Without considerable preparation of the surface the finish reproduced is of a lower standard than that obtainable from moulds of other materials. Furane resins which are black, may be used to advantage for the surface finishing of wooden moulds.

Female moulds of G.R.P. permit the reproduction of a very high surface finish and being more stable are adopted to a considerable degree. The female moulds require, however, the production of a male former from which the G.R.P. female mould may be "lifted."

Having the mould of a different colour from that of the resin assists the operator in identifying that a constant thickness of resin gel coat, which is most desirable, is being obtained.

Parting Agents.

A parting agent has to be applied to the surface of the mould to prevent the sticking of the laminate. Suitable agents may be hard (carnauba) wax, polyvinyl alcohol (P.V.A.), cellulose acetate solution or a proprietory preparation.

The application of a parting agent to a mould surface with epoxide resin is also recommended for although polyester resin (the type more usually used) will not adhere to epoxide resin, the latter, in some cases until very thoroughly cured, exudes a very faint trace of free phenol which inhibits the cure of the polyester resin.

Lay-Up.

Gel Coat.—The lay-up is commenced by the application (by brush, roller or spray) of a resin coat, usually pigmented, to the surface of the mould. This forms the outside of the laminate and its name is derived

from the fact that further laying-up does not proceed until this resin layer has "gelled" (surface hardened).

It is applied to prevent the texture of the glass reinforcement becoming visible on the surface on shrinkage of the resin, forms a resin surface over the exterior to prevent ingress of water vapour by capillory action along the glass filaments, and prevents the reinforcement from being rolled through to the external surface when laying-up.

The gel coat resin besides being normally thixotropic should, to prevent star shakes and feathery lines appearing in the external surface, contain a certain proportion of flexibiliser.

Surface Reinforcement.—To support the gel coat a surface reinforcement of glass scrim cloth or surface tissue is often incorporated. A further layer of resin is applied to the gel coat, reinforcement laid on, and the resin is worked thoroughly through the reinforcement using rollers or squeegees, etc.

Main Lay-up.—Then follows the incorporation into the laminates of the resin and glass layers to provide the appropriate mechanical properties required.

Resin coats are applied, each being followed by the laying, on the wet resin, of one thickness of the glass reinforcement specified. The resin is forced through the reinforcement by roller or squeegee on each occasion. This procedure is continued until the thickness and strength of the laminate has been built up.

Where thick laminates are being made continuous lay-up is not advised because the high exotherm built up in the relatively large amount of resin can exceed acceptable limits, causing blistering, etc. It is preferable to lay-up in phases allowing the exotherm to dissipate.

Internal Stiffeners.—When the "shell" has been laid-up as required, framing, ribs, or local stiffening and/or reinforcement for fastenings, etc., are incorporated.

Internal Finish.—The internal finish of a lay-up particularly with mat reinforcement is poor and can be improved by the addition of a resin coat and a layer of glass surface tissue.

Completion.—The completed laminate should be allowed to remain in the mould for at least 24 hours unless the recommended post heat is applied, when the laminate may be removed earlier.

The laminate will continue to cure for a period after removal from mould. In some instances this full cure takes a considerable period if post heat is not applied, and it is advisable to brace large laminates for a few days after removal from the mould.

Where a boat hull is concerned, unless post heat is applied, it should not be put in the water for at least 7 days after removal from mould.

The post heat is approximately 80-100° F. and should be applied indirectly, *i.e.*, electrical heaters around outside of mould, raising the

temperature of the building or infra red lamps, etc. Too strong heating before resin gels can result in blistering and delamination.

Advantages and Disadvantages of the Hand Lay-Up Method.

An important aspect of this type of lay-up is that the reinforcement may be varied to suit the designer's requirements. For instance, where it is preferable to dispense with any internal framing in certain areas, then the skin can be increased gradually in thickness as the framing is gradually diminished ; or where special strength fittings have to be incorporated, the skin may be built up to provide adequate local strength for the fastenings of the fittings.

Temperature and humidity controlled buildings are necessary (as manufacturers have found to their cost).

The glass content by this method is low, between 25 to 35% (by weight), and strengths are relatively low.

Quality of product is variable because of the human element.

Skilled oversight and checking of the resin mixes is essential.

Careful sequence of operations is necessary.

Vacuum Bag Method.

This method is employed on larger mouldings. It is less dependent upon operators' skill in laying-up and higher glass contents are possible.

The principle is to exhaust the air from between the mould and the shaped bag which is sealed around the edges of the mould. Atmospheric pressure on the bag then applies up to about 14 lb./sq. inch pressure on the laminate.

The laminate is usually laid up in a manner similar to that described for the hand lay-up method. The bag (often transparent) is fitted over the inside and sealed. The vacuum is applied and any air in the laminate is worked out by hand.

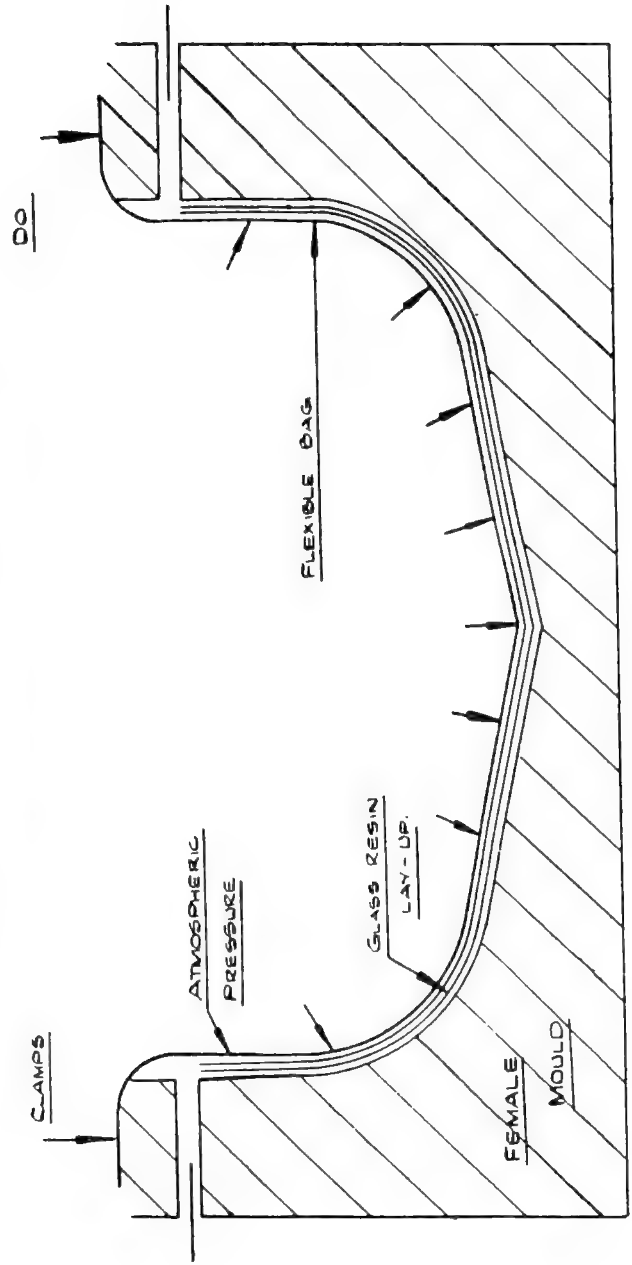
The Pressure Bag Method.

This method is also used for large mouldings, being similar to the vacuum bag principle except that the bag is forced against the laminate by higher pressure. It requires a more robust mould as pressures up to 50 lb./sq. inch can be applied.

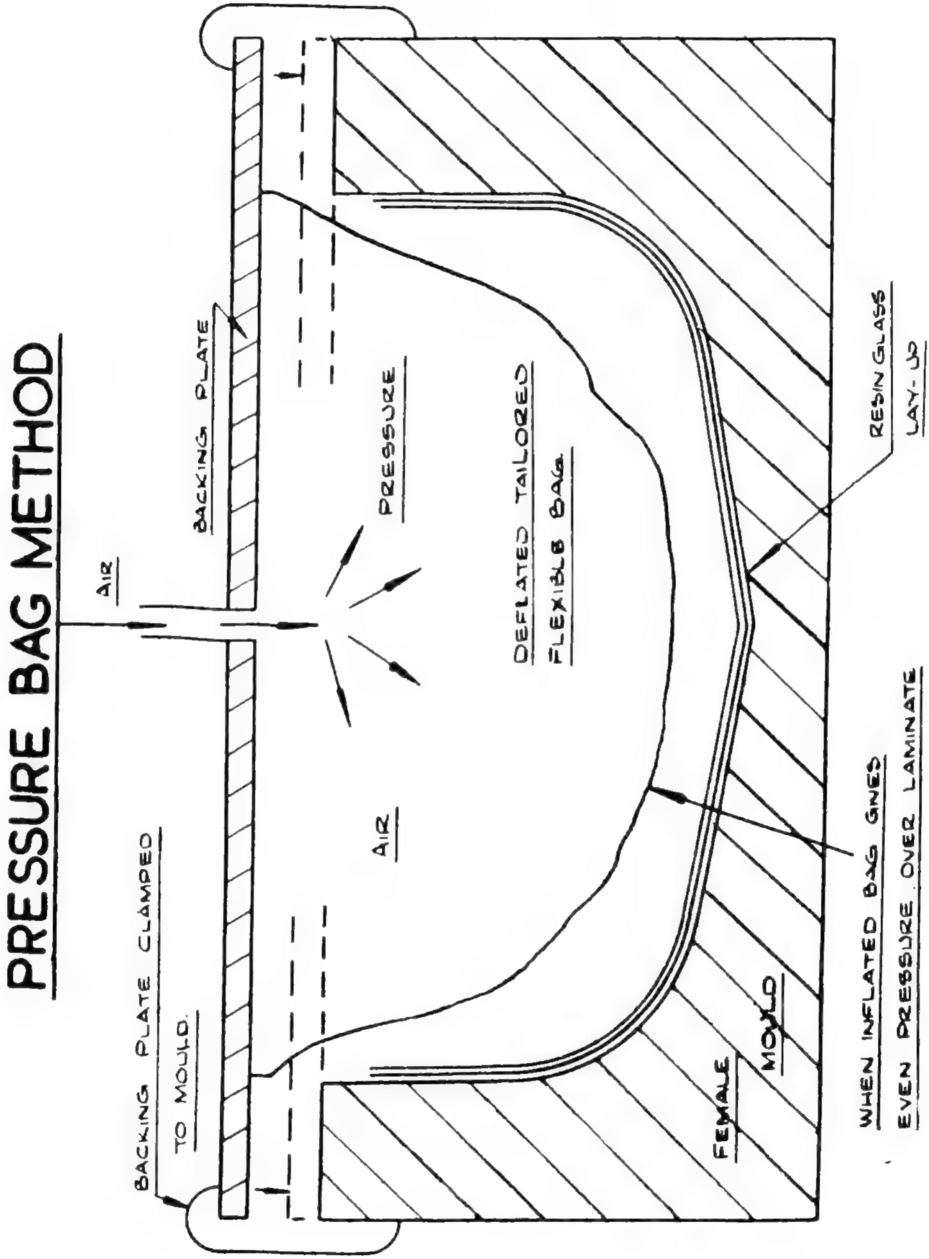
Autoclave Moulding.

This is a method by which the pressures applied in the vacuum bag technique are increased. The process is as for the vacuum bag method except that the mould is placed in an autoclave containing hot air at pressures of 50-100 lb./sq. inch.

Phenolic/glass laminates which require heat and pressure often employ this principle.



VACUUM BAG METHOD


PRESSURE BAG METHOD
AIR
BACKING PLATE
PRESSURE
DEFLATED TAILORED FLEXIBLE BAG
RESIN GLASS LAY-UP
AIR
BACKING PLATE CLAMPED TO MOULD.
FEMALE MOULD
WHEN INFLATED BAG GIVES EVEN PRESSURE OVER LAMINATE

Injection Moulding.

This method is used for large and small mouldings and requires matching male and female moulds which, although relatively light in construction, makes it expensive in comparison with the previous methods described for the larger mouldings.

It gives a rather low glass content and therefore strengths are not high.

The resin is drawn up slowly when the vacuum is applied. It tends to flow around obstructions or closely packed glass. If the glass reinforcement does not fill the space between the moulds, a thick layer of resin on one side results.

Variable strengths in the one laminate are liable with this method, but can, with experience, be minimised.

Pressure injection is now being used and is capable of giving close tolerance moulding and also low resin contents to a fair degree of uniformity. It can be used as a direct pressure or in conjunction with a vacuum.

Flexible Plunger Method.

This method is used primarily for small mouldings and is similar in principle to the pressure bag method.

Precision made heated female moulds are required. The reinforcement is laid in the mould and the resin poured over. Solid rubber or neoprene male plugs, shaped such that under pressure fit the female moulds exactly, are then applied. The moulds are erected in a press and pressures up to 150 lb./sq. inch may be applied.

Matched Die Moulding.

Usually employed for large scale production of relatively small articles. Very expensive tooling costs are involved and seldom justified unless more than 1,000 articles are required.

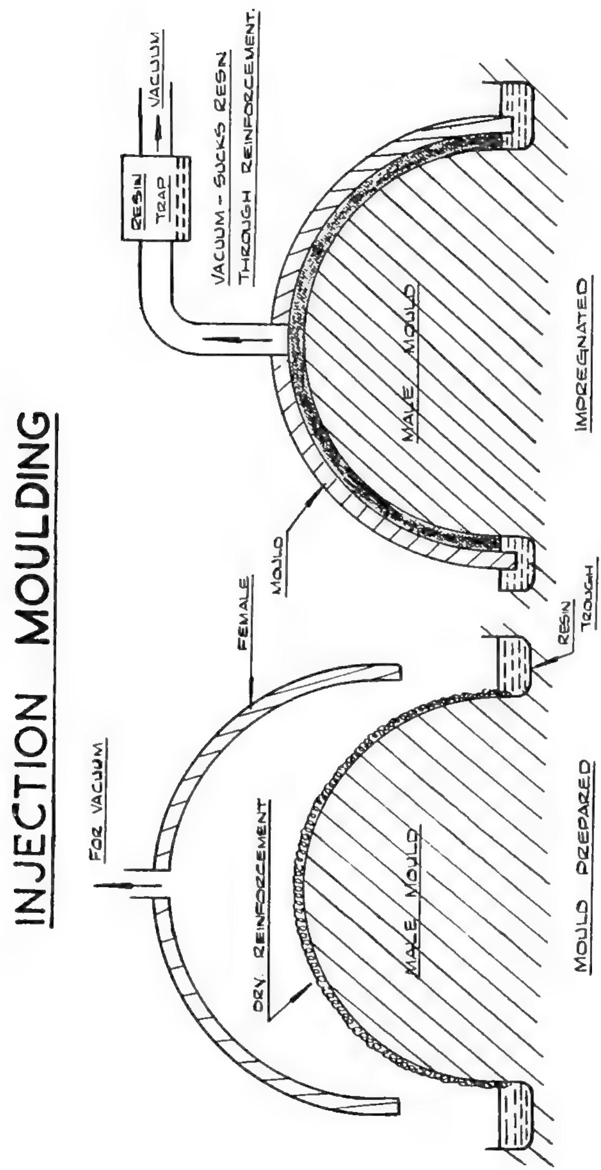
Pressures vary between 50 and 500 lb./sq. inch and are associated usually with high curing temperatures to accelerate production.

This method gives a high glass content and high strength.

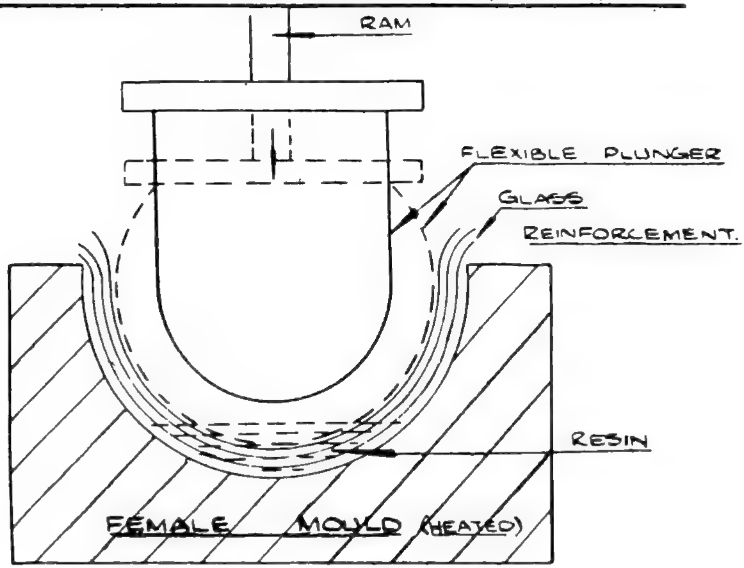
Hand lay-up, vacuum and pressure bag methods are normally used for the production of large structures—methods such as injection moulding, flexible plunger method and matched die moulding being adopted for only the comparatively small articles. Other methods of production are castings (normal and centrifugal, etc.), preforming (by mechanical means) extrusions, pottings and continuous laminating of sheets (by mechanical process), etc.

The use of mechanical spraying methods for applying a mixture of chopped glass filaments and resin to the surface of moulds is increasing.

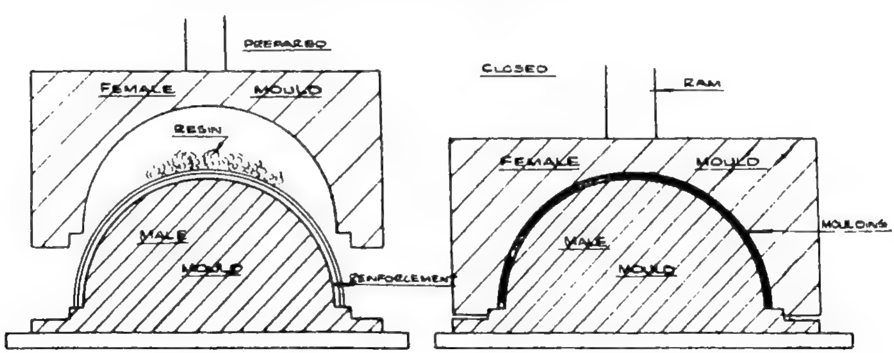
The use of glass cloth pre-impregnated with an undercured resin is a relatively new technique which is being experimented with.


INJECTION MOULDING
FOR VACUUM
FEMALE
MOULD
DRY REINFORCEMENT
MALE MOULD
RESIN
TROUGH
MOULD PREPARED
RESIN
TRAP
VACUUM
VACUUM - SUCKS RESN
THROUGH REINFORCEMENT.
MALE MOULD
IMPREGNATED

FLEXIBLE PLUNGER METHOD



MATCHED DIE MOULDING



MOULDS MALE AND FEMALE HEATED

SECTION V.

INSPECTION.

The quality of a laminate depends to a great extent upon the ability of the operators. Inspection is therefore of great importance. The following notes relate mainly to the inspection of "hand lay-up," polyester resin laminates, as these are the more common types adopted by industry.

The relevance of some of the remarks to other methods of production will be apparent.

Methods of Inspection.

Standard non-destructive methods of inspection and test are being sought for G.R.P. but, in general, the inspection of an article is by visual means.

Visual inspection is greatly assisted by using clear resin throughout the laminate or by pigmenting the external resin coat(s) only and using clear resin for the rest of the lay-up. Seen against the light, or with a bright light on the remote side, flaws in such a laminate are readily discernible.

Other methods of inspection are to weigh the complete articles, drop or impact test and to take test pieces for chemical or physical tests, tensile and flexural strengths, etc.

Inspection Prior to Commencing Manufacture.

Glass Reinforcements.

Check materials supplied to ensure they are as per specification, *e.g.*, weave, count, alkali content, sizes, binders or finishes, etc.

Check dry storage of the reinforcement.

Resins.

Obtain the recommendations of the resin manufacturers for resin mixes, gel times, working temperatures, curing cycles, post heat and phasing.

Check from sample resin mixes (gel coat and main lay-up) that the proportions proposed produce the correct results.

Establish the sequence of operations to ensure that the phasing is suitable to the particular resin to be used.

Moulds.

Inspect the moulds, female and/or male, for dimensional accuracy and finish.

Oversee the preparations of the mould with release agents.

Sample Laminates.

For prototypes the production of sample laminates prior to commencement is recommended to establish resin/glass ratio, water absorption and strength, etc., are within the design requirements.

During Lay-Up.

Working Conditions.

Check at regular intervals the ambient temperature and humidity of the workshop to ensure that they are within the limits laid down by the resin manufacturer.

Materials.

Inspect the glass reinforcement for imperfections. If any are found assessment will be required as to their acceptance or rejection.

Witness periodically the mixing of the resin and addition of filler (if specified).

Keep a detailed account of the amounts of materials used. (This will provide an indication of consistency of resin/glass ratios).

Handling.

Keep a continual and close surveillance of the handling of the materials and the actual lay-up. (Irrespective of the control exercised for the materials, the ultimate responsibility for the quality of a laminate produced by hand lay-up falls upon the operator. If thorough wetting out and impregnation of the glass reinforcement is not carried out, with the associated removal of all air, then the mechanical properties of the laminate could suffer appreciably).

Check that the phasing and sequence of operations is being maintained.

Check that post cure, if applied, is in accordance with the resin manufacturers' recommendations.

After Laminate is Complete.

Release from Mould.

Check the need for bracing, if a large laminate, before permitting removal from the mould.

Attend the removal of a large laminate from the mould. (Areas of non-release and undercure will be immediately visible).

Inspection of Laminate.

Visual, for surface blemishes, flaws, resin rich or resin starved areas, air entrapment, etc.

Hardness Test, with such as a Barcol hardness meter or similar will indicate degree of cure of the internal and external resin coats.

Weight of the completed article, if obtainable, compared with materials incorporated will provide a check on the resin/glass ratio.

Testing.—If there is doubt with regard to a particular **structural** laminate, a small area of the suspected portion should be removed and subjected to laboratory test prior to the acceptance of the article.

SECTION VI.

FAULTS IN MANUFACTURE.

The following are some of the faults, and causes thereof, which occur due to incorrect manufacture. They are mainly related to the production of polyester/glass laminates by the hand lay-up method.

FAULT	CAUSES
Cracking and crazing of the resin.	Too high a catalyst or accelerator content. Too much resin bulk, *e.g.*, insufficient phasing of a thick laminate, etc. Lack of flexible resin component in gel coat. Too high temperature with post heat.
Blistering under the Surface.	Wrong type of binder or finish to the glass reinforcement. Resin starvation. Insufficient time allowed for resin to absorb the binder or finish. Unsatisfactory "wetting out" of the reinforcement, *e.g.*, incomplete rolling, etc.
Reduced resin to glass bond strength.	High humidity, *e.g.*, moisture on the surface of the glass filaments. Excess or incorrect type of fillers. Imperfect "wetting out" of the reinforcement. Undercure of resin (see later in table). Incorrect phasing of operations, *e.g.*, one part of a laminate, or a layer of a laminate, allowed to cure beyond a certain degree before proceeding.
Reduced strength of laminate.	Incorrect types of binder or finish to the glass reinforcement. Incorrect types of resin. Inhibition of cure of the resin (see Resin Section). Too high proportion of resin to glass. Reduced resin to glass bond strength. Too high filler content.

FAULT.	CAUSES.
Resin rich and resin starved areas.	Imperfections in the glass reinforcement. Lack of thoroughness in laying the reinforcement. Resin to viscous. Unsatisfactory dispersing of the resin over the reinforcement. Insufficient working of the resin through the reinforcement (particularly where there are difficult shapes and corners, etc.).
Surface faults.	Parting agent on mould—poor application or unsuitability, *e.g.*, polishes containing soft wax or silicones, etc. Gel coat resin—incorrect type, viscosity or mixing. —unsatisfactory application, *e.g.*, too thick or too thin. —extended gel time. —no flexibiliser in resin.
Undercure of the resin—partial or complete.	Incorrect working conditions, *e.g.*, low temperature or draughts. (Results in reduction of effective exotherm and loss of styrene). Dampness of the glass reinforcement—due to bad storage or high humidity. Extension of resin gel times—due to working conditions, too low a catalyst content (insufficient chemical reaction—cannot be accelerated by application of post heat or higher accelerator content) ; or too low accelerator content (post heat can, in this instance, possibly avoid undercure). Incorrect parting agents on moulds. Inhibitors—see Resin Section. Pigment—unsuitable or in excess. Fillers—unsuitable, damp, or in excess. Non-sealing of epoxide resins or putty on moulds, etc. Cleaning agents—acetones, ketones or special resin removing creams.
Variations in thickness.	Imperfections in the glass reinforcement. Too high resin to glass proportions. Insufficient working of the resin through the reinforcement.

SECTION VII.

PRECAUTIONS IN MANUFACTURE.

Precautions and safeguards are necessary when handling resins. Polyester resins do not affect the skin of most people, but epoxide resins usually incorporate amine hardeners which are dermatitic. The irritant potential of some of the epoxide resins coming on the market has been greatly reduced, but care is still necessary.

Barrier Creams.

The special barrier creams which give protection against resins should be applied to the hands, particularly round the finger nails and the fore-arms, before handling the resin. Creams should be applied irrespective of subsequent use of protective gloves.

Gloves.

Gloves should be worn when handling the organic peroxide catalysts for polyester or handling epoxide resins. "Throw away" type polythene gloves are available. Amine hardeners, after a time, penetrate rubber.

Goggles.

Goggles should be worn if there is a likelihood of resin splashing into the eyes and when sanding.

Masks.

Masks should be worn when sanding.

Ventilation.

Workplaces should be well ventilated in way of the operator, particularly when sanding and when using epoxide resins with amine type hardeners.

Dirty Bins.

Contaminated "throw away" gloves and rags should be deposited in bins kept for the purpose, and burnt. Rags contaminated with organic peroxides should be disposed of separately because of the danger of spontaneous combustion.

Cleaning of Tools.

Most resins are soluble in ketones. Acetone is used in industry for cleaning resin off tools before it has gelled. Once the resin is set it cannot be removed by cleansing agents. Acetone is inflammable ; considerable caution is required therefore and factory regulations

regarding inflammable liquids must be adhered to. Cleansing agents are available. Acetone and cleansing agents being resin solvents should be kept away from any laminating or incompletely cured laminates.

Acetone can be used as a degreaser on moulds, for repairs to laminates and cleaning surfaces of G.R.P. prior to painting. Must be used sparingly or suitably diluted.

Cleaning of Hands.

Washing facilities with running hot water, soaps, detergents and "throw away" type towels should be provided. Operators should wash their hands and forearms regularly. Acetone should not be used to clean resin from the hands as it removes natural oils from the skin. Cleansing creams are obtainable.

SECTION VIII.

BOAT CONSTRUCTION IN G.R.P.

Typical types of boat construction are here described.

Rib and/or Stringer Construction.

This method of construction uses the conventional principles of boat construction, *i.e.*, incorporating ribs and stringers to provide transverse and longitudinal strength and reduce panel size for impact resistance. It is used generally for large boats.

The ribs and stringers are fitted either after the last internal lay-up of the "shell" has been completed, but not cured ; or when all but the last layer of reinforcement has been laid, the final layer being laid over ribs and stringers.

The gunwales, engine bearers and hog are of timber through-bolted to rubbers, doublers and keel. In all instances the heads and nuts of strength fastenings should not be pulled up on G.R.P. It is for this reason that the G.R.P. is usually sandwiched between timber. Large flexible plastic washers can be used where no timber is fitted. Through bolts should be bedded in either the resin or flexible non-setting waterproof compound.

It is desirable to restrict the number of through fastenings, therefore a keel as indicated for Monocoque or Sandwich construction and engine bearers fastened to angles worked on the inside of the hull are recommended.

Monocoque Construction.

This principle of construction is being widely employed as it provides high class finish to seating, etc., as separate moulds are employed for hull, seating, decks and canopies. The flanges of the separate sections form longitudinals and with the "foam" under seats providing rigidity of the centre portion, further stiffeners are often not required for the smaller types of boat.

Care has to be taken in planning the sequence of construction if polyester resins only are employed to ensure assembly of the parts whilst the resin is only partially cured. Epoxide resins can be used to advantage in this respect ; each laminate can be allowed fully to cure then bonded in situ using the high adhesive properties of epoxides.

An alternative method of forming the seat structure that is sometimes adopted when foam material compatible with polyester resin is used is

to build up the G.R.P. seat covering direct on the foam which has been shaped and fitted in the seat positions. This method dispenses with the need for a separate seat moulding. It also simplifies obtaining a good fit or bond (if required) between the foam and the G.R.P.

Sandwich Construction.

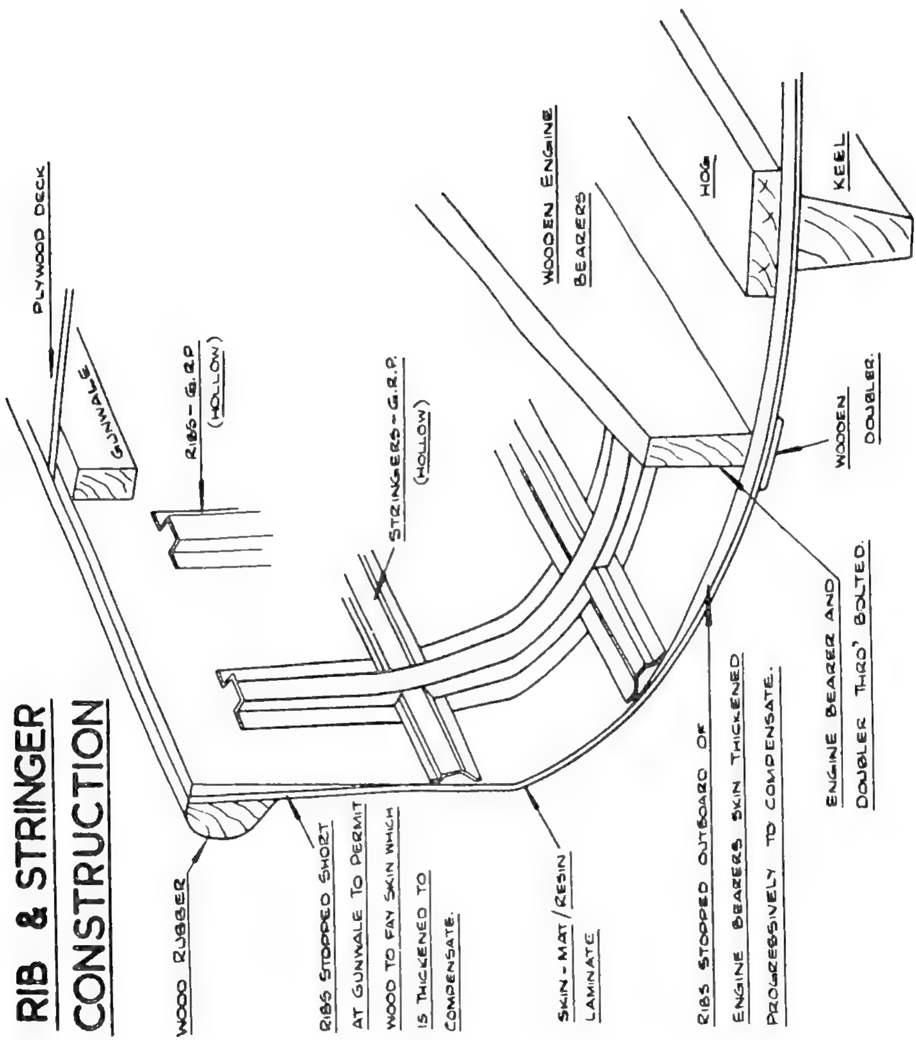
This type of construction has shown to be of advantage in the smaller types of powered craft as the buoyant material incorporated in the skin, besides contributing considerably towards making the boat fully buoyant (always a difficulty where small boats with large engines are concerned), also provides rigidity to the hull dispensing with the need for stiffening.

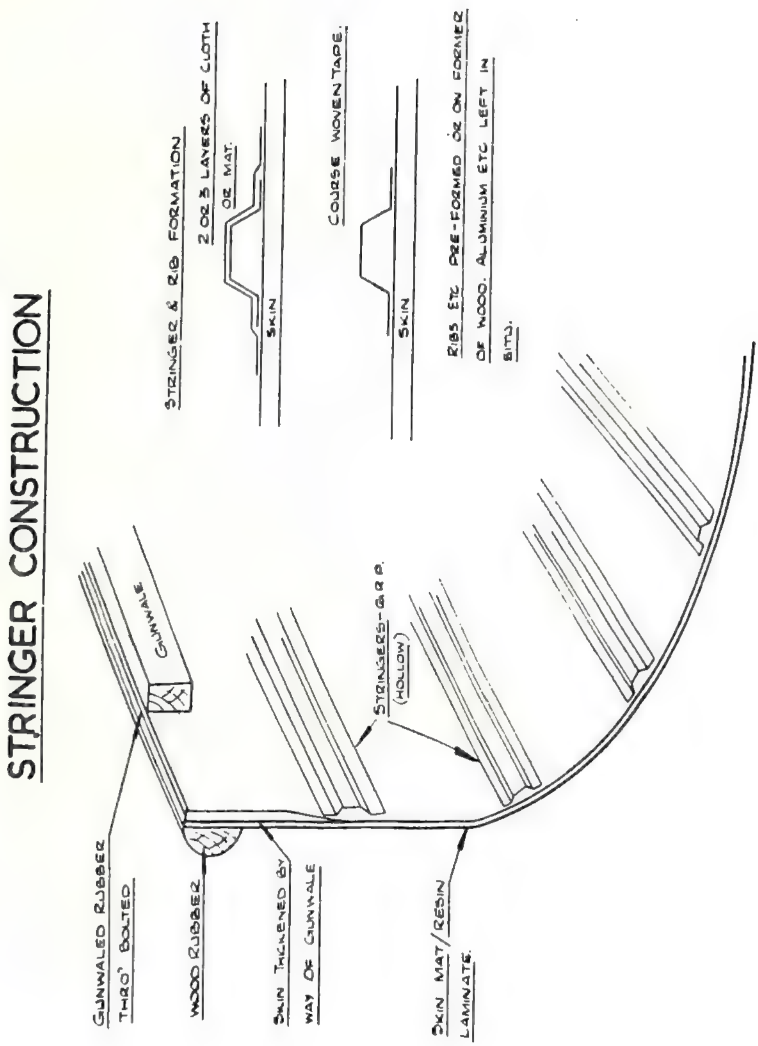
The buoyant material may be of polyvinyl chloride (P.V.C.) unicellular foam, or polyurethene foam. It must be of the type which is compatible with the polyester resin and of comparatively high density, otherwise the resin will soften the foam. The P.V.C. foam is usually used in sheet form, pre-formed to shape prior to laying up.

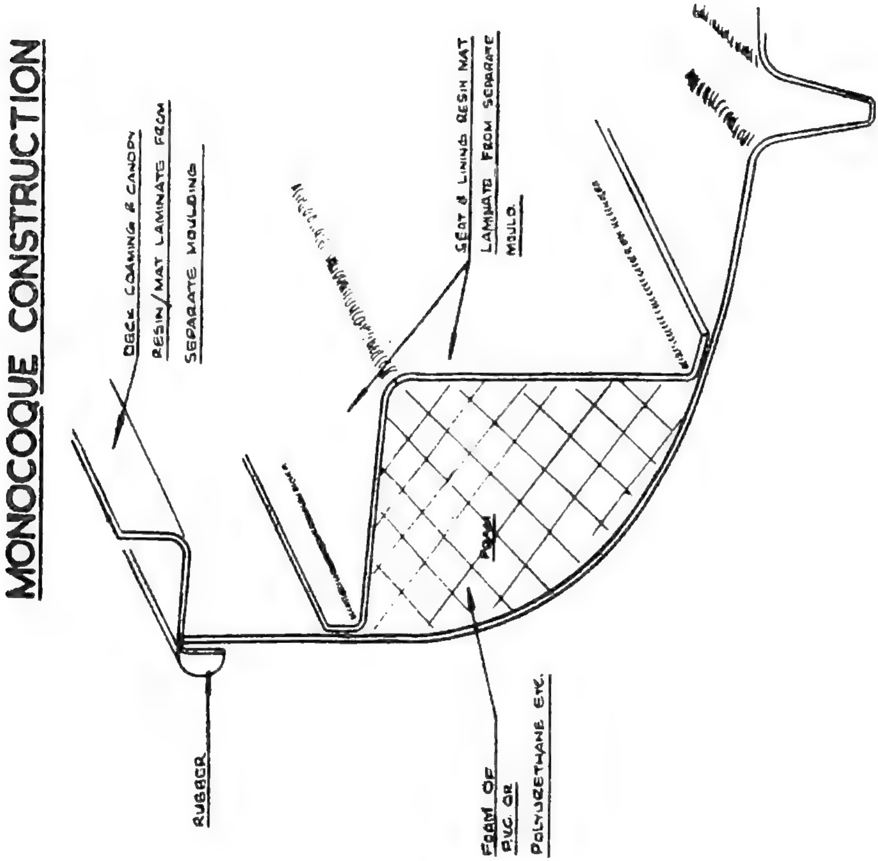
One aspect of sandwich construction is that where any securing of fittings, etc., is required an insert of timber, solid resin/glass and sometimes steel, has to be incorporated in place of the foam. This means close study of the design and all associated equipment at the very beginning so that securing pads can be incorporated where necessary. Once the lay-up is completed modification to lay-out, etc., where through fastenings are required, is limited.

If wood inserts are used they should be kiln dried. Some species of timber are unsuitable for this purpose and preservative treatment to the timber may inhibit the cure of the resins.

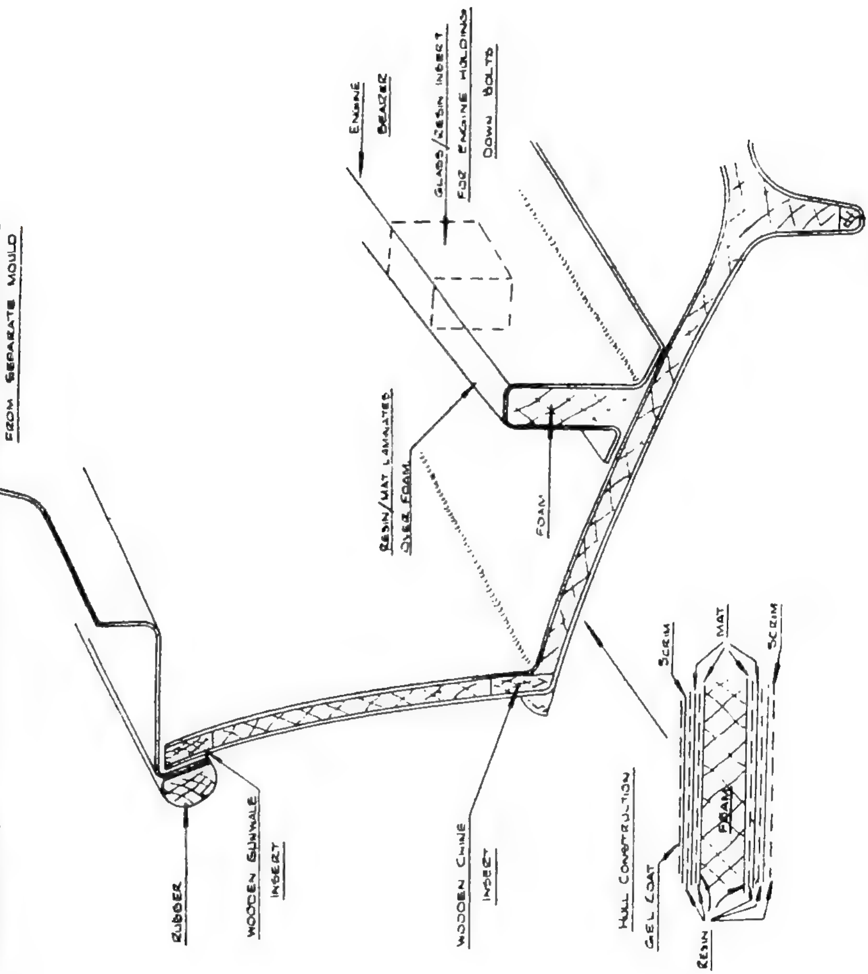
Other craft have been constructed with a timber "core," but of reversed sequence of manufacture, *i.e.*, the hull is produced with relatively low grade timber, carvel fashion without close fitting of the strakes and polyester glass laminates laid-up inside and out. The point about this method of construction is that the surface finish is not high, requiring a certain amount of finishing to produce a reasonable appearance. It does, however, avoid the need and cost of a female mould.


RIB & STRINGER CONSTRUCTION
PLYWOOD DECK
GUNWALE
RIBS - G.R.P (HOLLOW)
STRINGERS - G.R.P. (HOLLOW)
WOODEN ENGINE BEARERS
HOG
KEEL
WOODEN DOUBLER.
ENGINE BEARER AND DOUBLER THRO' BOLTED.
RIBS STOPPED OUTBOARD OF ENGINE BEARERS SKIN THICKENED PROGRESSIVELY TO COMPENSATE.
SKIN - MAT/RESIN LAMINATE
RIBS STOPPED SHORT AT GUNWALE TO PERMIT WOOD TO FAY SKIN WHICH IS THICKENED TO COMPENSATE.
WOOD RUBBER


STRINGER CONSTRUCTION
STRINGER & RIB FORMATION
2 OR 3 LAYERS OF CLOTH OR MAT.
SKIN
COURSE WOVEN TAPE.
SKIN
RIBS ETC PRE-FORMED OR ON FORMER OF WOOD, ALUMINIUM ETC LEFT IN SITU.
GUNWALE
STRINGERS-G.R.P. (HOLLOW)
GUNWALED RUBBER THRO' BOLTED
WOOD RUBBER
SKIN THICKENED BY WAY OF GUNWALE
SKIN MAT/RESIN LAMINATE.

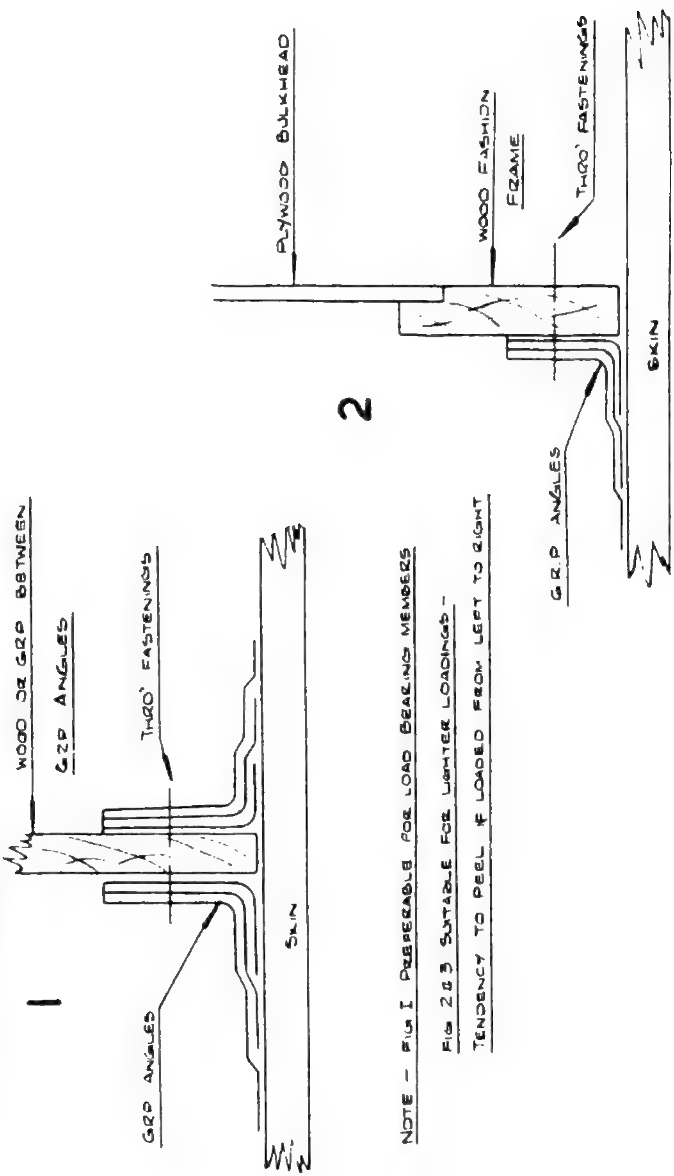

MONOCOQUE CONSTRUCTION
DECK COAMING & CANOPY
RESIN/MAT LAMINATE FROM
SEPARATE MOULDING
SEAT & LINING RESIN MAT
LAMINATE FROM SEPARATE
MOULD.
FOAM
RUBBER
FOAM OF
P.V.C. OR
POLYURETHANE ETC.

SANDWICH CONSTRUCTION



TYPICAL ANGLES, RIBS & BULKHEAD FORMATION

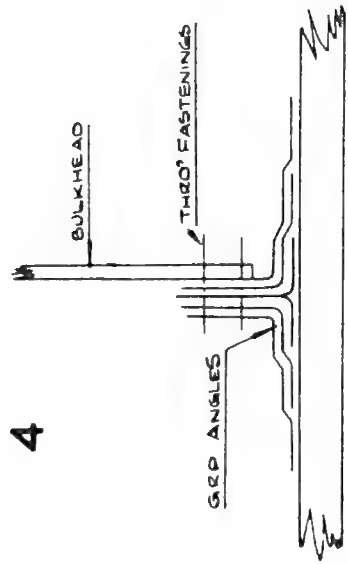
BULKHEADS.

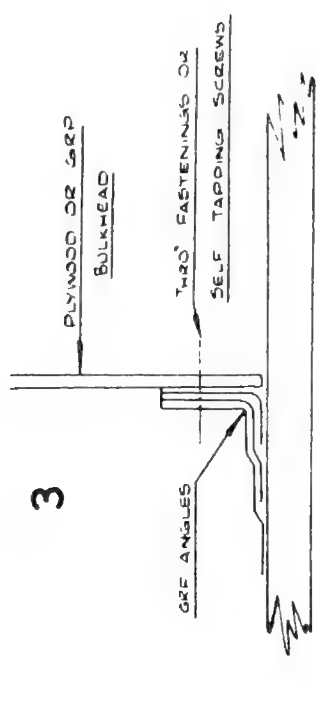


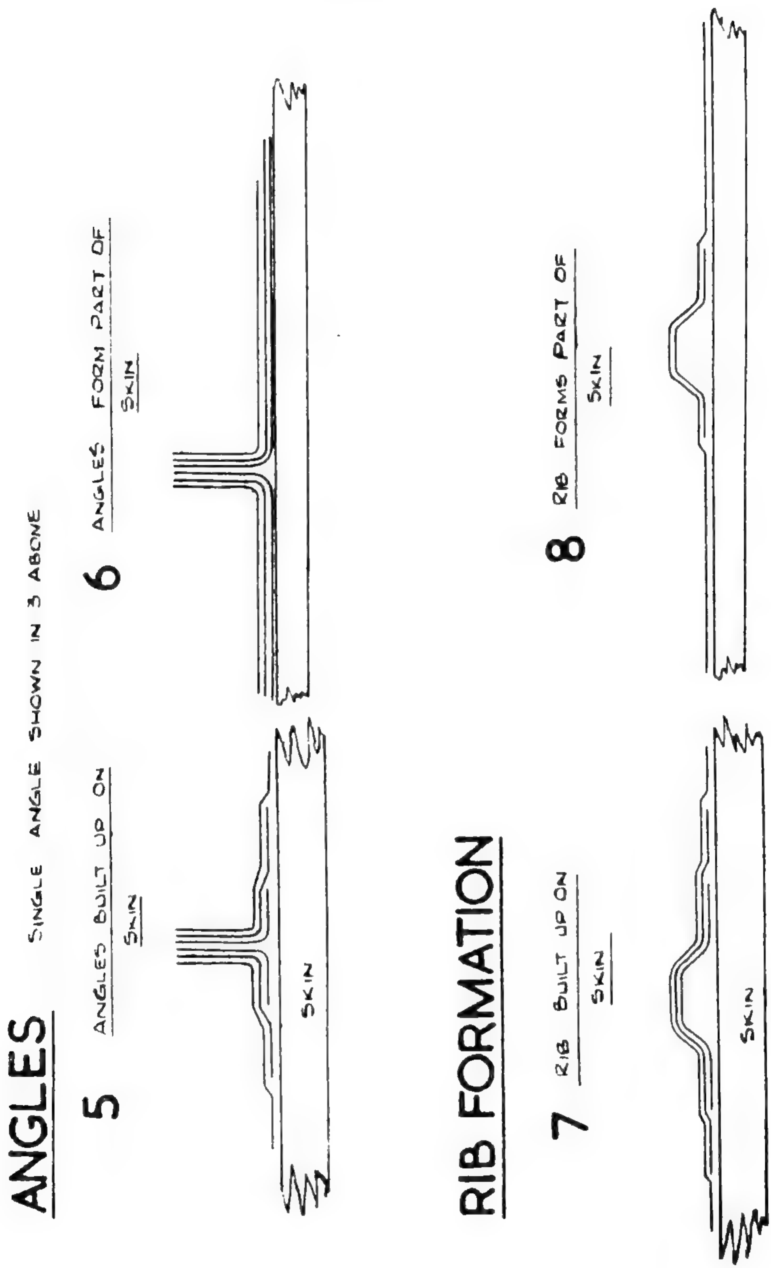
NOTE – FIG I PREFERABLE FOR LOAD BEARING MEMBERS

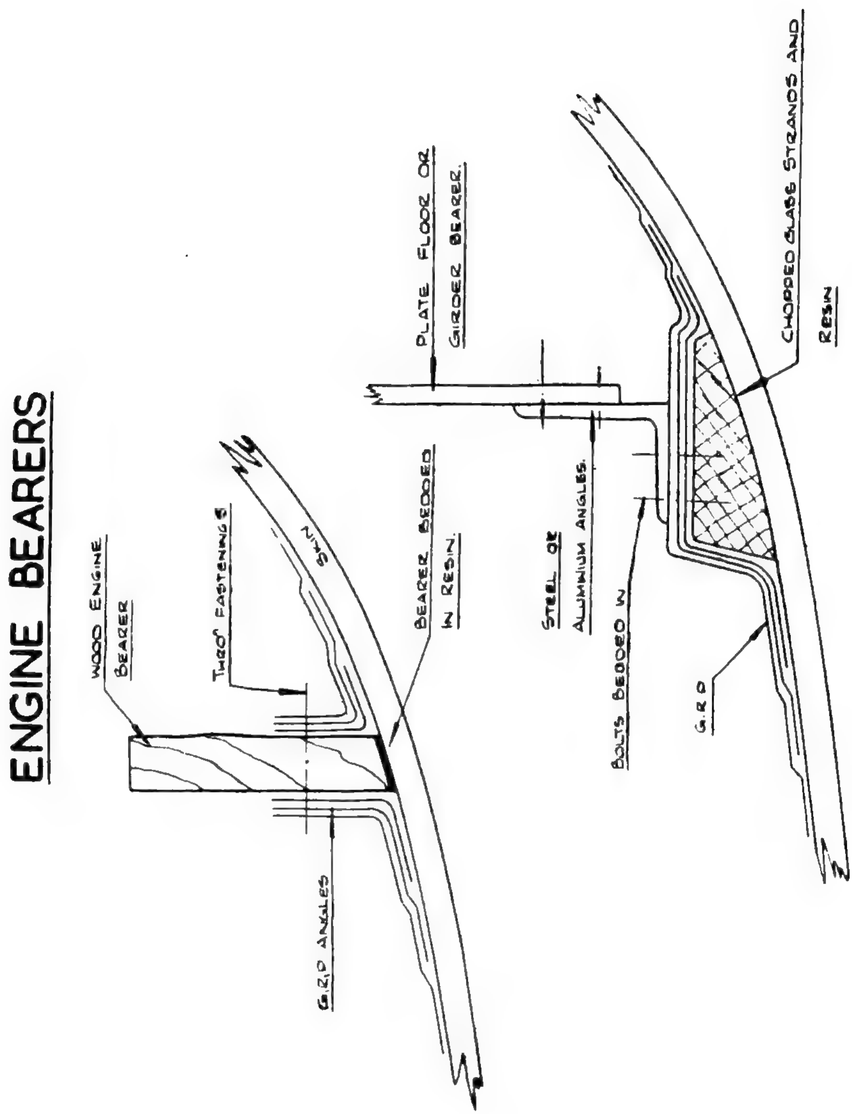
FIG 2 & 3 SUITABLE FOR LIGHTER LOADINGS –

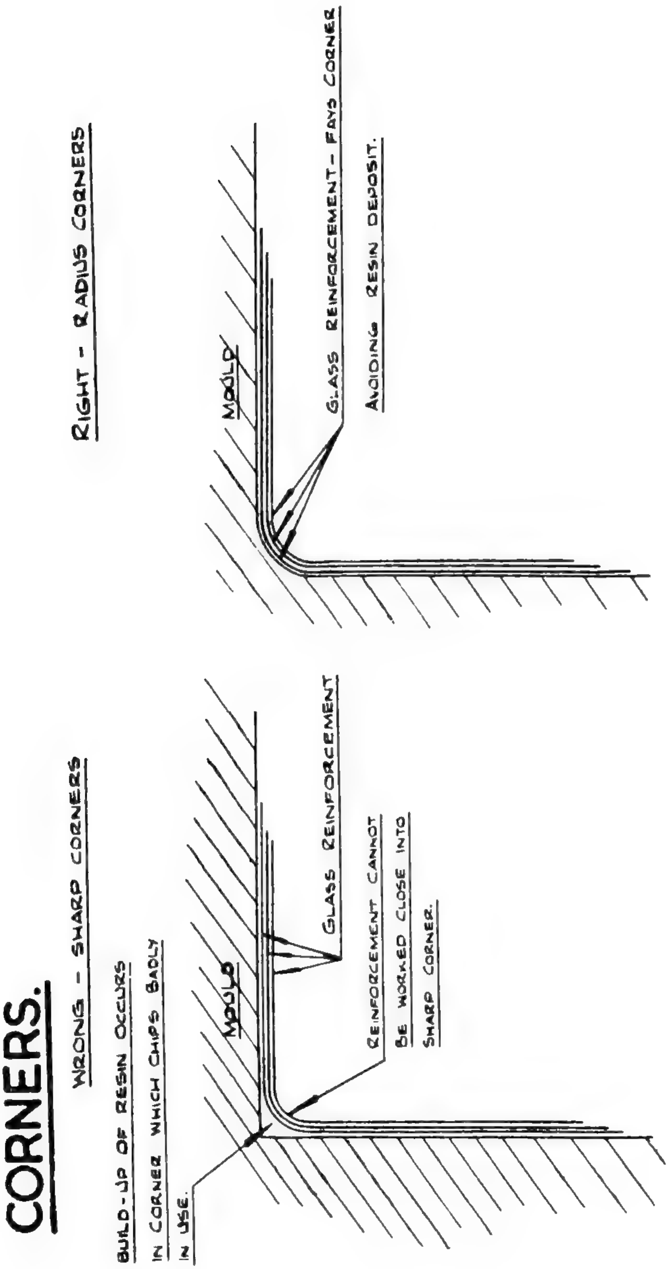
TENDENCY TO PEEL IF LOADED FROM LEFT TO RIGHT


4
BULKHEAD
THRO' FASTENINGS
GRP ANGLES


3
PLYWOOD OR GRP
BULKHEAD
THRO' FASTENINGS OR
SELF TAPPING SCREWS
GRP ANGLES


ANGLES
5 ANGLES BUILT UP ON SKIN
SINGLE ANGLE SHOWN IN 3 ABOVE
SKIN
6 ANGLES FORM PART OF SKIN
RIB FORMATION
7 RIB BUILT UP ON SKIN
SKIN
8 RIB FORMS PART OF SKIN


ENGINE BEARERS
WOOD ENGINE BEARER
THRO' FASTENINGS
SKIN
BEARER BEDDED IN RESIN.
G.R.P ANGLES
PLATE FLOOR OR GIRDER BEARER.
STEEL OR ALUMINIUM ANGLES.
BOLTS BEDDED IN
G.R.P
CHOPPED GLASS STRANDS AND RESIN


CORNERS.
WRONG - SHARP CORNERS
BUILD-UP OF RESIN OCCURS IN CORNER WHICH CHIPS BADLY IN USE.
MOULD
GLASS REINFORCEMENT
REINFORCEMENT CANNOT BE WORKED CLOSE INTO SHARP CORNER.
RIGHT - RADIUS CORNERS
MOULD
GLASS REINFORCEMENT - FAYS CORNER
AVOIDING RESIN DEPOSIT.

NOTES ON BOAT CONSTRUCTION.

For small boats the major requirement is impact resistance; for the larger craft longitudinal strength becomes the prime requirement.

Glass mat is one of the cheapest forms of reinforcement which provides bulk and exhibits good impact resistance. It has been adopted quite satisfactorily for some 95% or more of the G.R.P. boats built in the United Kingdom.

Layers of glass mat and woven rovings also exhibit extremely good impact resistance plus directional strength dependent upon the direction of the primary weave of the roving. This type of reinforcement using variations of mat and woven roving lay-up has been adopted to a considerable degree in the U.S.A. and Canada, and to some extent on the Continent. It is recommended that full consideration be given to this type of combination of reinforcements when boats of over 30 ft. in length are being designed.

Correct use of the properties afforded by the various glass reinforcements available can provide a degree of transverse and longitudinals strength for the larger boats permitting the number and size of ribs and/or stringers to be reduced.

Wooden hulls below 20 ft. in length have, in general, planking of the order of $\frac{3}{8}''$ thickness. G.R.P. hulls up to 27 ft. in length have "shells" of the order of $\frac{1}{8}''$ thickness. It follows therefore that unless a saving in the weight of structural members can be achieved by using G.R.P., the smaller G.R.P. boats, up to, say, 20 ft. in length, because of the relative specific gravities, will show little saving in weight over a conventional wooden boat and could well be heavier.

The weights of G.R.P. and wooden boats between 20 ft. and 30 ft. in length are generally considered comparable, but above 30 ft in length G.R.P. shows to advantage.

Sharp corners, such as at edge of transoms, should be avoided as the heavy resin deposit that results chips and breaks easily. (See sketch).

G.R.P. decks are slippery even when a criss-cross pattern has been incorporated in surface resin coat, and consideration should be given to the fitting of non-skid deck strips.

Consideration needs to be given to tumble home, reverse curvatures, etc., in the design in order that moulds may be made such that the laminate can be released and removed satisfactorily. Split moulds assist in this matter.

The absorption of machinery noises is less in a G.R.P. boat than in one of wooden construction. Flexible engine mountings assist in this respect.

Epoxide resins have not, so far, been adopted for the production of boat hulls (other than a few experimental craft) because to date there is

no evidence to indicate that the higher costs of epoxides are warranted or the increased strengths required when polyesters/glass laminates exhibit satisfactory properties for such applications.

Recommendations for Materials.

1. Low alkali or "E" glass reinforcement for all marine applications.
2. The external gel coats of boats' hulls should be with a laminating resin containing a proportion of flexible resin. Considerable star shakes and crazing occurs if no flexibiliser is added.
3. The use of fillers in resins should be avoided for laminates in the marine field.
4. The use of epoxide resins is advised when securing structural members of polyester resin when the polyester has fully cured.
5. Clear resins are suggested for other than the gel coat to facilitate oversight.

SECTION IX

MISCELLANEOUS DESIGN NOTES.

PHYSICAL PROPERTIES.

Abrasion Resistance of polyester and epoxide/glass laminates is not high, but can be increased by the use of appropriate fillers or surface reinforcements.

The use of Terylene in a laminate as a support for the gel coat, in lieu of glass scrim cloth or surface tissue, is increasing as improved weathering and chemical properties are claimed.

Anti-fouling .... G.R.P. does not possess anti-fouling properties, but the smooth external surface retards fouling and makes removal easier.

Certain fillers such as copper flakes, etc., in the external resin coat are said to improve anti-fouling properties.

Compatability with Other Materials.

Timber .... most species, with the exception possibly of teak, may be bonded with epoxide resins.

Most species, except teak and oak, may be satisfactorily bonded with polyester resins.

Ferrous and non-ferrous metals .... may be bonded with epoxide resins, although copper is difficult and requires special preparation. Bonding surfaces should be thoroughly degreased and if possible mechanically abraided.

Expanded Polystyrene is dissolved by polyester resins, but may be sealed and/or bonded with epoxide resins.

Expanded P.V.C. and Polyurathane may be bonded satisfactorily with polyester and epoxide resin.

Impact Strength .... G.R.P. exhibits good impact resistance associated with the types of resin and glass reinforcement used.

The following tup test results are an indication of the impact strengths :—

Tup, 11 lbs. weight, 2″ dia. dropped progressively at 1 ft. intervals.

Test laminates—polyester/glass, approx. $\frac{1}{8}$″ thick, produced by hand lay-up method.

Reinforcement	*Result*
(i) Scrim + 2 × 2 ozs. Mat.	Fractured at 5 ft. drop.
(ii) As (i), but with square weave woven roving between the mats.	4 in No. drops of 8 ft. required to cause fracture.
(iii) As (ii), but with the rovings on underside.	5 in No. drops of 8 ft. did not produce fracture.
(iv) As (i), but with 2 × 2 open weave woven roving between the mats.	2 in No. drops of 8 ft. caused fracture.
(v) As (iv), but with the roving on underside.	

(For comparison, wood panels of 2 in No. layers of $\frac{3}{16}''$ mahogany laid diagonally, either clenched together or glued, with Canadian rock elm ribs, $\frac{7}{8}'' \times \frac{3}{8}''$, spaced 4″ apart, fractured at a 5 ft. drop of the tup).

Machining of G.R.P. may be summarised :—

Sawing	coarse metal saws preferable.
Drilling, ...	carbide tipped drills and backing plates recommended.
Filing, ...	coarse files or rasps recommended.
Sanding, ...	coarse or fine discs suitable.
Turning and Milling,	not usual but possible.
Tapping, ...	coarse threads preferable (not a strength fastening.)

Detailed information on machining, drilling, counter-sinking, bolting and rivetting are contained in "Fibreglass Reinforced Plastics," by Sonneborn.

Resin/Glass Ratios—the optimum glass content for maximum strength is between 60-70% by weight.

The average glass contents of a laminate by the different methods of production may be summarised :—

Method.	*Glass Content (approx.).*
Hand lay-up, ...	25-30%
Vacuum bag moulding, ...	30% plus
Pressure bag moulding, ...	35-45%
Autoclave moulding, ...	35-45%
Flexible plunger moulding, ...	35-45%
Matched die moulding, ...	50-65%
Resin injection moulding, ...	10-20%
Pressure moulding, ...	40-60%

Recently improved resins and glass finishes produce higher glass contents.

Shrinkage—percentage shrinkage of resins on curing are by volume :—

Polyester resins, ...	4-7%
Epoxide resins, ...	0·3-2% maximum.
Phenolic resins, ...	8-10%

Specific Gravities.

Polyester resin, ...	1·1-1·3
Epoxide resin, ...	1·1-1·2
Glass reinforcement (low alkali), ...	2·55
Glass ,, (alkali), ...	2·46
Polyester/glass laminates with 35% mat content (by weight), ...	1·5-1·6
Polyester/glass laminates with 50-60% woven rovings (by weight), ...	1·7-1·9
Epoxide/glass laminates with 60-65% cloth content (by weight), ...	1·8

Tensile Strength of G.R.P. is dependent upon the resin, type and proportion ; glass reinforcement, weave, finish and content ; filler and method of manufacture.

Considerable strength criteria is available in publications. In view of the wide scatter of results, an indication of average tensile strengths of hand lay-up laminates produced under workshop conditions only are given.

Reinforcement.	*Glass Content.*	*U.T.S.*
Glass mat, ...	25%	5-7 tons/sq. inch.
Light woven cloth,	35%	9 ,, ,,
Square weave cloth,	40%	13 ,, ,,

Stress strain curves for G.R.P. are fair and almost straight with yield point seldom visible.

ESTIMATING.

(For Polyester/Glass Laminates).

Quantities.

Hand Lay-Up Method.

Type of glass reinforcement	*Approximate Resin Requirements*
Chopped strand mat, ...	$2\frac{1}{2}$ times weight of reinforcement.
Woven cloths, ...	1-$1\frac{1}{2}$ times weight of reinforcement.
Scrim cloth or surface tissue,	$1\frac{1}{2}$ ozs. per sq. ft.
	Gel coats—$1\frac{1}{2}$-2 ozs./sq. ft.

Pressure Impregnation.

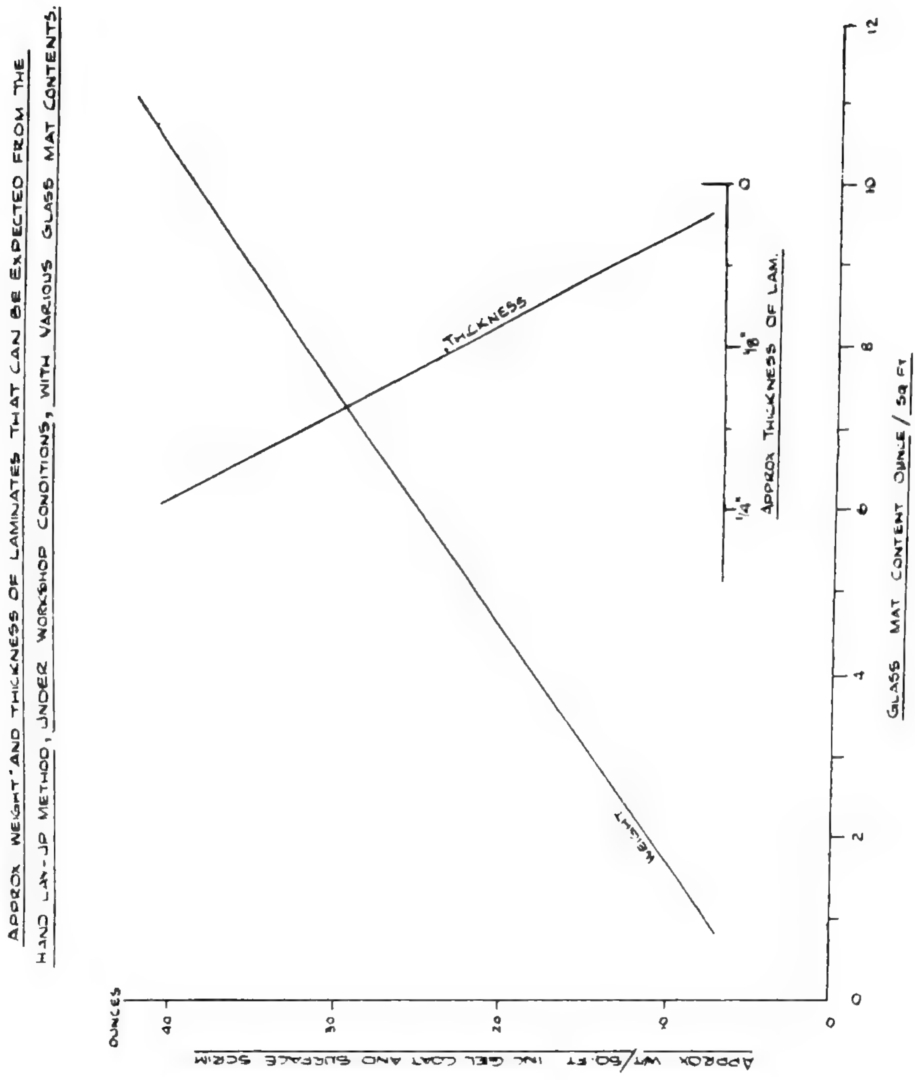
Type of Glass Reinforcement	*Approximate Resin Requirements*
Chopped strand mat, ...	$1\frac{1}{2}$ times weight of reinforcement.
Woven cloths, ...	$\frac{3}{4}$-1 times weight of reinforcement.

Example.

Laminate, produced by hand lay-up method, consisting of gel coat, two layers of 2 ozs./sq. ft. glass mat and one layer of woven rovings at, say for simplicity, 1 oz./sq. ft.

Resin required—gel coat	=	2 ozs.
mat 2×2 ozs $\times 2\frac{1}{2}$	=	10 ozs.
roving $1 \times 1\frac{1}{2}$	=	$1\frac{1}{2}$ ozs.
		$13\frac{1}{2}$ ozs./sq. ft.
Reinforcement weight	=	5 ozs./sq. ft.
Weight of resin/glass laminate	=	$18\frac{1}{2}$ ozs./sq. ft.

Thickness.


APPROX WEIGHT AND THICKNESS OF LAMINATES THAT CAN BE EXPECTED FROM THE HAND LAY-UP METHOD, UNDER WORKSHOP CONDITIONS, WITH VARIOUS GLASS MAT CONTENTS.
THICKNESS
WEIGHT
0
1/8"
1/4"
APPROX THICKNESS OF LAM.
0
2
4
6
8
10
12
GLASS MAT CONTENT OUNCE / SQ FT
OUNCES
40
30
20
10
0
APPROX WT/SQ.FT INC GEL COAT AND SURFACE SCRIM

Costs.

From quantities, costs per square foot of laminate, excluding labour and mould costs, are obtained.

Very approximate cost of materials :—

Polyester resin	2/6 to 4/- per lb. (in bulk)
Epoxide resin	7/6 to 12/- per lb. (in bulk)
Glass mat	5/- per lb.
Glass woven rovings	7/6 per lb.
Glass cloths	10/- per lb.

(Material costs of polyester/glass laminates (mat reinforcement) are approximately twice the cost of steel, epoxide/glass laminates 3½-4 times the cost).

DESIGN CONSIDERATIONS.

Method of manufacture.

Type of resin.

Type(s) of glass reinforcement.

Shape suitable for moulding.

Release of laminate with reverse curvature, splitting of mould to assist.

Curved surfaces—to minimise stiffening.

Corners radiused.

Edge flanges—for stiffness.

Stiffeners incorporated integral with main lay-up (where possible).

Local reinforcement for fastenings or higher stressed areas incorporated integrally.

Phasing of operations with polyester resins

Weight—specific gravities are high.

Economy—glass reinforcement is expensive.

SECTION X.

REPAIR OF G.R.P.

G.R.P. laminates can be repaired using either polyester or epoxide resins with a glass reinforcement and the following notes relate to the use of the different resins, glass reinforcement and methods employed.

Polyester Resin Repairs.

Polyester resins are more suitable for workshop repairs as draught free conditions and an ambient temperature above 60° F. are required. Under such conditions a perfectly satisfactory repair can be effected. For important structural repairs the use of polyester resins is, however, not recommended as the strength of the bond on a cured polyester laminate may vary considerably.

Numerous repair kits containing thixotropic polyester resins are available and are suitable for repair and filling of G.R.P. boats and car bodies, etc. Some have inhibitors incorporated in the components to prolong shelf life. Others, in order to reduce the number of components, have predetermined amounts of accelerator incorporated in the resin. A further variation, to simplify measuring, the components are supplied in predetermined quantities.

Advantages.

Cheapness.

Ease of handling for large non-structural repairs.

Disadvantages.

Limited shelf life.

Special storage required	—preferably below 40° F.
	—catalyst and accelerator to be kept separate in view of explosive danger.
	—fire risk.
Limited working conditions	—temperature, draught and humidity limitations.
Measuring of quantities	—careful measuring required (particularly accelerator where only a small percentage is required).
	—three components are preferable for control under various climatic conditions, but predetermined amounts are essential.
	—accelerator in resin does not provide sufficient control for variation in climatic conditions.

Epoxide Resin Repairs.

Where structural repairs ; repairs under adverse conditions of draughts and low temperature ; or where longer storage life with reduced limitations on storage are required epoxide resins are advised.

They are more expensive than polyester resins. Have to be carefully selected for bond strength as some are completely unsuitable for repair applications. For repairs "in the field" by personnel unaware of the dermatitic hazards one of the "practically safe" epoxide resin systems is strongly advised.

Repair kits are becoming available containing thixotropic epoxide resins and hardeners and are eminently suitable for shipborne repair kits. The remarks that follow relate to at least one specific resin/hardener repair system.

Advantages.

Two year shelf life.

Practically no storage limitations.

Usable over a wide range of temperatures.

High bond strength—unaffected by draughts.

Simple mixing—two components in predetermined quantities.

Once gelled will cure underwater (important for boat repairs).

Suitable for semi-permanent repairs to double skin wooden boats.

Good adhesive properties to a wide range of materials.

Extremely unlikely to cause dermatitis.

Disadvantages.

Expensive—two to three times cost of polyester resin.

Glass reinforcement has to be carefully selected—compatibility to resin and ease of wetting-out.

Usually more viscous—unless carefully chosen for wetting-out properties, can be difficult to work.

Epoxide resin putty is suitable for the filling of scores and chipped areas and the remarks as for epoxide resin generally apply, except that it is not necessary to add a glass reinforcing material.

Glass Reinforcement for Repairs.

The prime requirements for the glass reinforcement included in a repair kit are :—

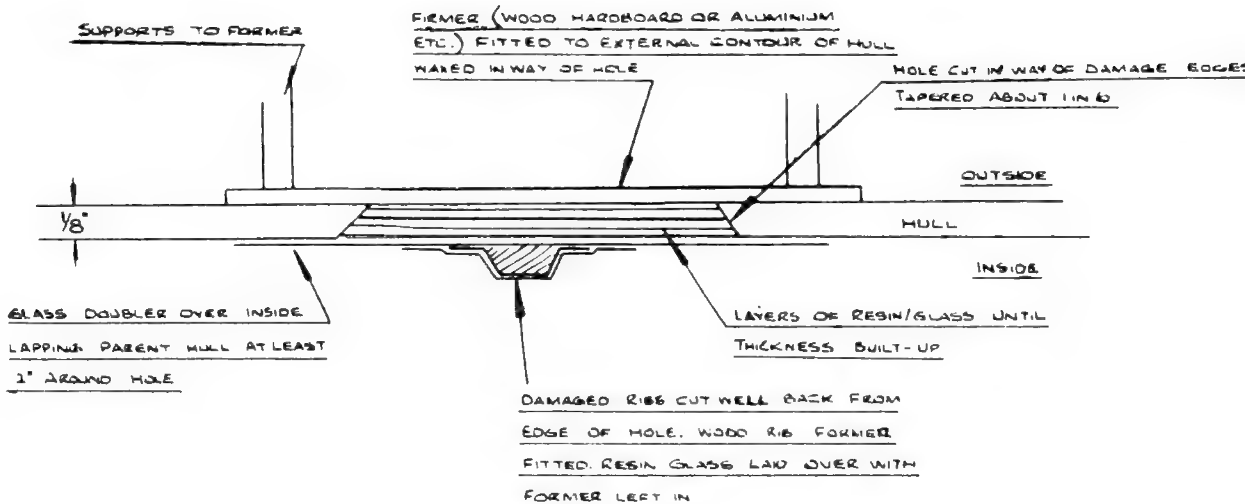
(i) non-fraying on cutting to shape of repair.
(ii) good wetting-out properties to simplify operations.
(iii) good draping characteristics—in case required.
(iv) strength of repair laminate comparable with parent material.

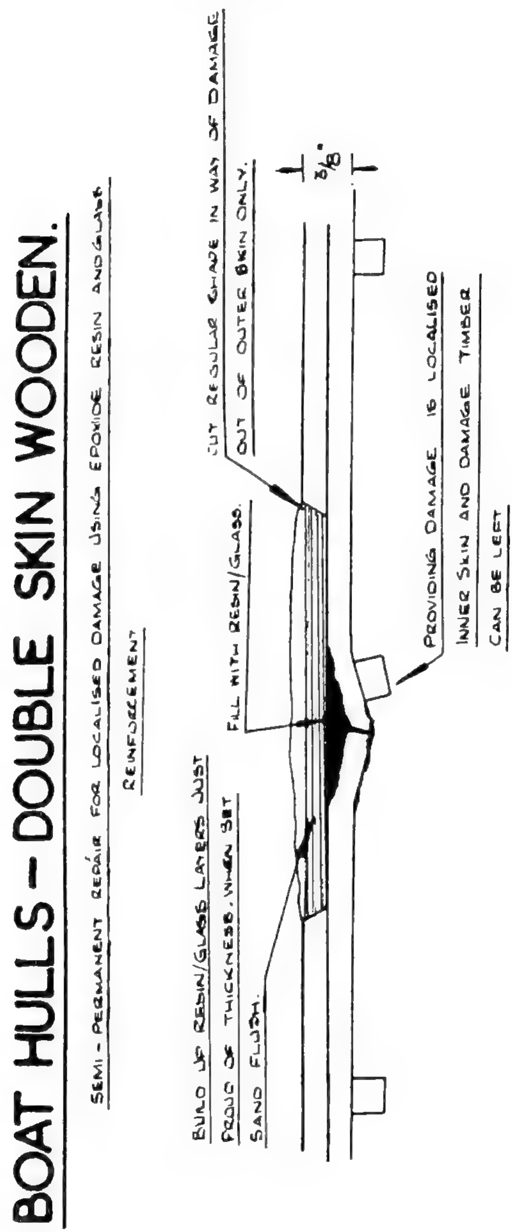
The suitability of the various glass reinforcements can be summarised :—

Woven cloths	Frays on cutting. Usually requires more layers to build up to thickness of parent laminate. Provides strength. Mock leno weave cloth very easy to handle, does not fray, good wetting-out properties. Exhibits resin rich areas, relatively weak on impact. Expensive.
Woven rovings	Frays badly on cutting. Not easy for the inexperienced to wet-out. Provides strength with bulk.
Chopped strand mats	Standard types pull apart on cutting. Difficult to work with a viscous resin, *e.g.*, some epoxides. New type mats do not pull apart on cutting. Suitable for use with epoxide resins. Can be used for repair of holes and ribs or stiffeners. Provides impact strength.

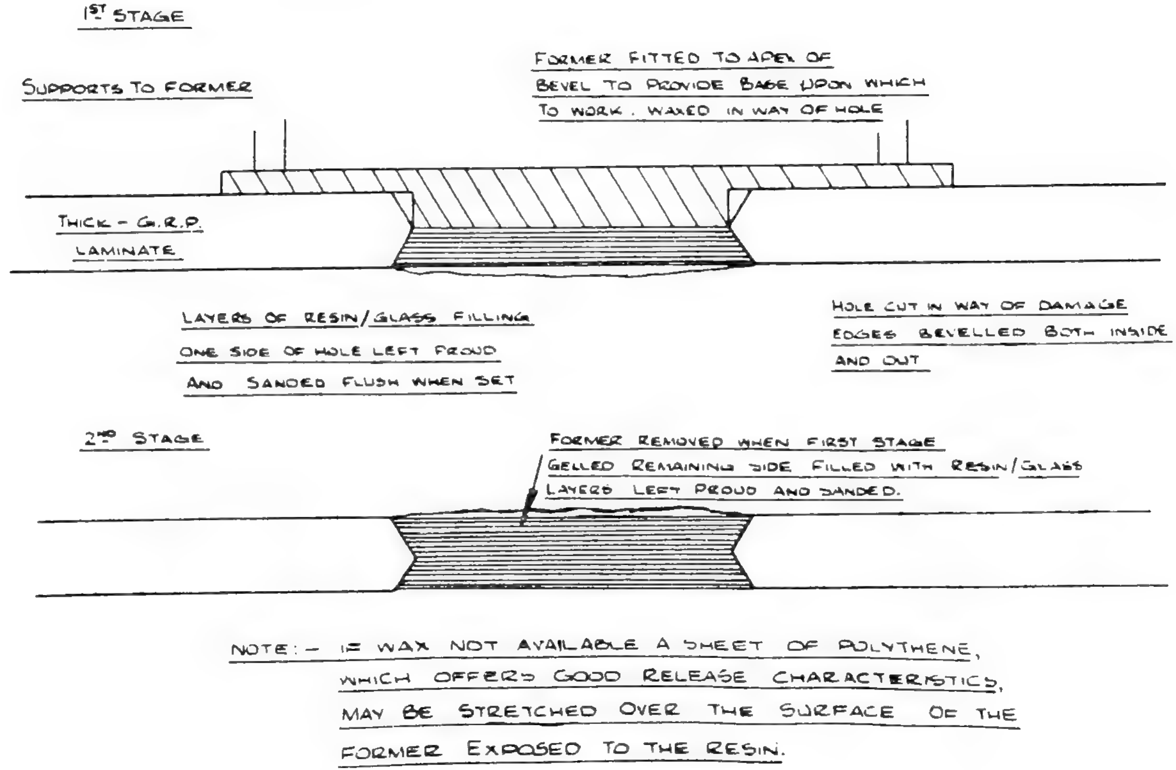
METHODS OF REPAIR

BOAT HULLS G.R.P.




BOAT HULLS – DOUBLE SKIN WOODEN.
SEMI - PERMANENT REPAIR FOR LOCALISED DAMAGE USING EPOXIDE RESIN AND GLASS REINFORCEMENT
BUILD UP RESIN/GLASS LAYERS JUST PROUD OF THICKNESS. WHEN SET SAND FLUSH.
FILL WITH RESIN/GLASS.
CUT REGULAR SHAPE IN WAY OF DAMAGE OUT OF OUTER SKIN ONLY.
3/8"
PROVIDING DAMAGE IS LOCALISED INNER SKIN AND DAMAGE TIMBER CAN BE LEFT

THICK LAMINATES



ACKNOWLEDGMENTS.

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BOOKS OF REFERENCE.

Fibreglass Reinforced Plastics, by Ralph H. Sonneborn, published by the Reinhold Publishing Corporation, 430 Park Avenue, New York, 22. 1954.

Plastics in the Service of Man—A Pelican publication. 1956.

Glass Reinforced Plastics (2nd edition), by P. Morgan, published by Iliffe & Sons, London. 1960. (1st edition, 1954).

Plastics, Theory and Practice, by C. C. Winding and R. L. Hasche, published by McGraw-Hill, London. 1947.

Synthetic Resins and Allied Plastics, by R. S. Morrell, published by Oxford University Press, London. 1951.

Plastics Progress published by Iliffe & Sons, London. 1953.

Relevant British Standards.

B.S. 2782—Methods of Testing Plastics.

Part 1—1956	Effect of Temperature (10/-).
Part 2—1957	Electrical Properties (5/-).
Part 3—1957	Mechanical Properties (7/6).
Part 4—1958	Analytical Methods and Viscosity in Solution (6/-).
Part 5—1958	Miscellaneous Methods (10/-).

B.S. 1755	1951	Glossary of Terms Used in the Plastics Industry (8/6).
B.S. 777	1954	Synthetic Resin (Phenolic) Moulding Materials (contains information re various tests in Appendices).

American Society for Testing Materials.

Considerable number of test procedures contained in Part 9 of A.S.T.M.'s 1958 edition :—

D.1044-56	Abrasion resistance.
D. 790-58T	Flexural.
D. 785-51	Hardness.
D. 256-56	Impact.
D. 732-46	Shear.
D. 638-58T	Tensile.
E. 41-57T	Conditioning and weathering
D. 756-56	Accelerated service conditions.
D. 570-57T	Water absorption.
D. 494, 834, 1303, 1505, 1603, etc.,	Analytical tests.
D.1600-58T	Abbreviation of terms re plastics.
D. 883-58T	Definition of terms.

SOME OF THE MORE GENERAL TERMS IN THE PLASTIC INDUSTRY.

(For a more complete "Glossary of Terms used in the Plastic Industry," see British Standard Publication 1755/1951).

Accelerator—A substance which increases catalytically the hardening rate of a synthetic resin.

Ageing—The change in properties of a material with time under stated conditions.

Base—The reinforcing material used in a laminate.

Balanced Cloth—A cloth where weft and warp strengths are approximately equal.

Bond—The linkage between atoms within a molecule.

Catalyst—A chemical compound which initiates polymerisation of a resin.

Cold Moulding—A process of manufacture of plastic articles in which a moulding composition is shaped in a mould at normal room temperature and is subsequently hardened after removal from the mould by chemical action with or without the application of heat.

Contact Laminating—A process of manufacture of laminated plastics in which the applied moulding pressure does not exceed that necessary to ensure contact between laminations.

Crazing—Minute cracks which appear on the surface of a laminate. Occurs mainly in resin rich areas.

Crimp—A measure of the amount of extra travel from a straight path that the yarn in a woven reinforcement must make in passing under and over the crossing threads. Degree of crimp is proportional to the number of the intersections the yarns make and the diameter of the crossing threads.

Cure—The process of hardening a thermosetting moulding composition under the influence of heat.

Curing Time (Moulding Time)—In the moulding of thermosetting plastics, the interval of time between the instant of cessation of relative movement between the moving parts of a mould and the instant that pressure is released.

Delamination—Breakdown of the structure of a laminated plastics material by the separation of the layers.

Dimensional Stability—The ability of a body or piece of material to maintain its shape or dimensions with changes in the nature or condition of its environment and, more particularly, with variation in atmospheric humidity.

Exotherm—The rise in temperature which results from a chemical reaction where heat is liberated.

Filler—An inert solid substance (*e.g.*, woodflour, china-clay), which is added to a synthetic resin to modify its properties. Fillers form an essential part of many plastic compositions.

Finish—See surface treatment.

Gelling Time (Setting Time)—The time taken for a resin to set to a non-fluid gel state.

Hardener—A material used to promote the setting of certain types of synthetic resin.

Impregnation—The process of controlled penetration of a material or an article with a synthetic resin.

Inhibitor—A material which effects the polymarisation preventing, either partially or fully, the cure of the resin.

Insert—An integral part of a plastics moulding consisting of metal or other material which may be moulded into position or may be pressed into the moulding after the completion of the moulding operation.

Laminating—The process of building up and consolidating the layers of a laminated plastics material.

Lay-Up—The positioning in the mould and impregnation of a reinforcement with resin.

Maturing Time—The time taken for an apparently fully cured resin to become completely stable.

Monomer—A substance composed of molecules which are capable of reacting with like or unlike molecules to form polymers.

Moulding Shrinkage—The difference in dimensions, expressed in inches per inch, between a moulding and the mould cavity in which it was moulded, both the mould and the moulding being at normal room temperature when measured.

Plasticizer—(*a*) A liquid or solid of low vapour pressure at ordinary temperatures used to modify the flow properties of a synthetic resin or of a composition based on a synthetic resin.

(*b*) A non-volatile substance incorporated with film forming materials in a paint, varnish or lacquer to improve the flexibility of the dried film.

When used in a resin composition, a plasticizer dissolves the resin or swells it by intermolecular penetrates and thus decreases its viscosity under the conditions of manufacture or use.

Polymer—A substance composed of very large molecules which consist essentially of recurring structural units.

Polymerization—The formation of polymers from simpler molecules.

Polyester—A polymer in which the structural units are linked by ester groupings obtained by condensation of one or more polycarboxylic acids (and if desired a minor proportion of a monocarboxylic acid) with one or more polyhydric alcohols (and if desired a minor proportion of a monohydric alcohol).

Post Heat—Application of indirect heat after moulding to complete, or accelerate cure of the resin.

Pot Life—The time, at room temperature, that a catalysed resin is usable.

Release Agent—A mould separating compound, or lubricant.

Resin Pocket—A defect in a moulding consisting of a space occupied by resin which has separated from the filler.

Retarder—A material which slows down the rate of cure of a resin (opposite to accelerator).

Setting Time—See gelling time.

Shelf Life—The maximum storage time for which a material remains usable.

Size—See surface treatment.

Square Weave—A plain weave with the same number of ends and picks per inch and having the same counts of yarn for weft and warp.

Surface Treatment—A material which is applied to fibrous glass during the forming or subsequent processes, *i.e.*, size or finish.

Thermoplastic—Having the property of softening repeatedly on the repeated application of heat and of hardening when cooled.

Thermosetting—Having the property of hardening on the application of sufficient heat (curing), and of not softening subsequently on the further application of heat.

Thixotropy—The condition of fluid of high apparent viscosity which when stirred or agitated becomes a mobile liquid.

Undercure—A condition of the moulded article, in the process of moulding thermosetting plastics, which arises when insufficient time and/or temperature has been allowed for adequate thermal hardening of the moulding.

Uni-directional Cloth—A cloth with high strength in one direction (either weft or warp), as compared with the other.

Viscosity—The ratio of the shear stress to the rate of shear of a fluid.

Water Absorption—The increase in weight of a test specimen of defined dimensions after immersion in water for a specified time at a specified temperature.

Yarn—Strands which have been twisted, or two or more twisted strands which have been plied.

D.A.T.A. PRINTED PAMPHLETS AND OTHER PUBLICATIONS IN STOCK

An up-to-date list of D.A.T.A. pamphlets in stock is obtainable on application to the Editor, *The Draughtsman*, Onslow Hall, Little Green, Richmond, Surrey.

Readers are asked to consult this list before ordering pamphlets published in previous sessions.

LIST OF D.A.T.A. DATA SHEETS

1. Safe Load on Machine-Cut Spur Gears.
2. Deflection of Shafts and Beams.
3. Deflection of Shafts and Beams (Instruction Sheet). — Connected.
4. Steam Radiation Heating Chart.
5. Horse-Power of Leather Belts, etc.
6. Automobile Brakes (Axle Brakes).
7. Automobile Brakes (Transmission Brakes). — Connected.
8. Capacities of Bucket Elevators.
9. Valley Angle Chart for Hoppers and Chutes.
10. Shafts up to $5\frac{1}{2}$ inch diameter, subjected to Twisting and Combined Bending and Twisting.
11. Shafts, $5\frac{3}{4}$ to 26 inch diameter, subjected to Twisting and Combined Bending and Twisting.
12. Ship Derrick Booms.
13. Spiral Springs (Diameter of Round or Square Wire).
14. Spiral Springs (Compression).
15. Automobile Clutches (Cone Clutches).
16. " " (Plate Clutches).
17. Coil Friction for Belts, etc.
18. Internal Expanding Brakes. Self-Balancing Brake Shoes (Force Diagram).
19. Internal Expanding Brakes. Angular Proportions for Self-Balancing. — Connected.
20. Referred Mean Pressure Cut-Off, etc.
21. Particulars for Balata Belt Drives.
22. $\frac{7}{8}''$ Square Duralumin Tubes as Struts.
23. $1''$ " " " "
24. $\frac{3}{4}''$ Square Steel Tubes as Struts (30 ton yield).
25. $\frac{7}{8}''$ " " " " (30 ton yield).
26. $1''$ " " " " (30 ton yield).
27. $\frac{3}{4}''$ " " " " (40 ton yield).
28. $\frac{7}{8}''$ " " " " (40 ton yield).
29. $1''$ " " " " (40 ton yield).
30. Moments of Inertia of Built-up Sections (Tables).
31. Moments of Inertia of Built-up Sections (Instructions and Examples). — Connected.
34. Capacity and Speed Chart for Troughed Band Conveyors.
35. Screw Propeller Design (Sheet 1, Diameter Chart).
36. " " " (Sheet 2, Pitch Chart). — Connected.
37. " " " (Sheet 3, Notes & Examples).
38. Open Coil Conical Springs.
39. Close Coil Conical Springs.
40. Trajectory Described by Belt Conveyors (Revised, 1949).
41. Metric Equivalents.
42. Useful Conversion Factors.
43. Torsion of Non-Circular Shafts.
44. Railway Vehicles on Curves.
46. Coned Plate Development.
47. Solution of Triangles (Sheet 1, Right Angles).
48. " " " (Sheet 2, Oblique Angles).
49. Relation Between Length, Linear Movement and Angular Movement of Lever (Diagram and Notes).
50. Relation Between Length, Linear Movement and Angular Movement of Lever (Chart).
51. Helix Angle and Efficiency of Screws and Worms.
52. Approximate Radius of Gyration of Various Sections.
53. Helical Spring Graphs (Round Wire).
54. " " " (Round Wire). — Connected.
55. " " " (Square Wire).

56. Relative Value of Welds to Rivets.
58. Graphs for Strength of Rectangular Flat Plates of Uniform Thickness.
59. ,, Deflection ,, ,, ,, ,, ,,
61. Deflection of Leaf Spring.
62. Strength of Leaf Spring.
63. Chart Showing Relationship of Various Hardness Tests.
64. Shaft Horse-Power and Proportions of Worm Gear.
65. Ring with Uniform Internal Load (Tangential Strain). } Connected.
66. ,, ,, ,, ,, ,, (Tangential Stress).
67. Hub Pressed on to Steel Shaft. (Maximum Tangential Stress at Bore of Hub).
68. Hub Pressed on to Steel Shaft. (Radial Gripping Pressure Between Hub and Shaft).
69. Rotating Disc (Steel) Tangential Strain. } Connected.
70. ,, ,, ,, Stress.
71. Ring with Uniform External Load, Tangential Strain. } Connected.
72. ,, ,, ,, ,, ,, Stress.
73. Viscosity Temperature Chart for Converting Commercial to Absolute Viscosities. } Connected.
74. Journal Friction on Bearings.
75. Ring Oil Bearings.
76. Shearing and Bearing Values for High Tensile Structural Steel Shop Rivets in Accordance with B.S.S. No. 548/1934.
78. Velocity of Flow in Pipes for a Given Delivery. } Connected.
79. Delivery of Water in Pipes for a Given Head.
80. (See No. 105).
81. Involute Toothed Gearing Chart.
83. Variation of Suction Lift and Temperature for Centrifugal Pumps.
89. Curve Relating Natural Frequency and Deflection.
90. Vibration Transmissibility Curved or Elastic Suspension. } Connected.
91. Instructions and Examples in the Use of Data Sheets, Nos. 89 and 90.
92. Pressure on Sides of Bunker.
93-4-5-6-7. Rolled Steel Sections.
98-9-100. Boiler Safety Valves.
102. Pressure Required for Blanking and Piercing.
103. Punch and Die Clearances for Blanking and Piercing.
104. Nomograph for Valley Angles of Hoppers and Chutes.
106. Compound Cylinder (Similar Material) Radial Pressure of Common Diameter (D.1).
107. True Angles for Pipe Bends.
108. Development of Spiral Chutes.
109. Vertical Pitch of Panels in a Frame with Bracing at a Constant Slope.
110. Permissible Stresses in Cranes—B.S. 2573. Table 1—Values of A & B Tons/Sq. In.
111. Permissible Stresses in Cranes—B.S. 2573. Table 2—Values of A & B Tons/Sq. In.
112. Permissible Stresses in Cranes—B.S. 2573. Table 3—Compressive Stresses in Axially Loaded Struts.
113. Permissible Stresses in Cranes—B.S. 2573. Table 4—Power Driven Rivets and Fit Bolts.
114. Permissible Stresses in Cranes—B.S. 2573. Table 5—Power Driven Rivets and Fit Bolts.
115. Rectangular Weld Groups with Eccentric Load in Plane of Weld.
116. Pipe and Plate Bends.

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Drawings for illustrations should be done either on a good plain white paper or tracing cloth, deep black Indian ink being used. For ordinary purposes they should be made about one-and-a-half times the intended finished size, and it should be arranged that wherever possible these shall not be greater than a single full page of the pamphlet, as folded pages are objectionable, although, upon occasion, unavoidable. Where drawings are made larger, involving a greater reduction, the lines should be made slightly heavier and the printing rather larger than normal, as the greater reduction tends to make the lines appear faint and the printing excessively small in the reproduction. In the case of charts or curves set out on squared paper, either all the squares should be inked in, or the chart or curve should be retraced and the requisite squares inked in. Figures should be as self-evident as possible. Data should be presented in graphical form. Extensive tabular matter, if unavoidable, should be made into appendices.

Authors of pamphlets are requested to adhere to the standard symbols of the British Standards Institution, where lists of such standard symbols have been issued, as in the case of the electrical and other industries, and also to the *British Standard Engineering Symbols and Abbreviations*, No. 1991, published by the B.S.I. at 6/-. Attention might also be given to mathematical notation, where alternative methods exist, to ensure the minimum trouble in setting up by the printer.

The value of the pamphlet will be enhanced by stating where further information on the subject can be obtained. This should be given in the form of footnotes or a bibliography, including the name and initials of the author, title, publisher, and year of publication. When periodicals are referred to, volume and page also should be given. References should be checked carefully.

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For pamphlets, a grant of £50 will be made to the author, but special consideration will be given in the case of much larger pamphlets which may involve more than the usual amount of preparation.